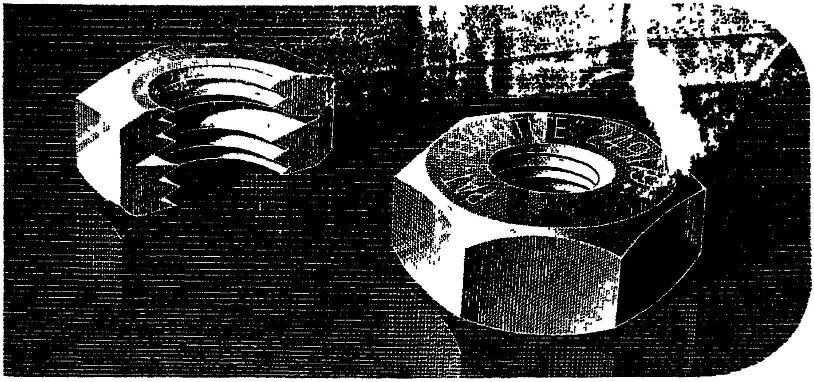

COLE'S PERMANENT WAY

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MATERIAL, MAINTENANCE, POINTS AND CROSSINGS

BY

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TENTH EDITION

Completely Rewritten

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PREFACE TO THE TENTH EDITION

MORE than fifty years have elapsed since the late Mr. W. H. Cole wrote this standard work, then containing only ninety pages. For the last three editions I have been responsible. In accordance with the wise policy of the Publishers, this edition has been almost entirely recast and re-written. It includes modern methods demanded by *ever heavier loads running at increasing speeds*. It deals with all gauges and gives examples of practice almost all over the world, a claim which is believed to be unique.

The first chapter deals with standards and components of track, entering into their specifications and manufacture only in so far as the Permanent Way man should know why components differ in composition Recent researches into track stresses and their effects are described. Perhaps the most startling innovation has been the modification of long standing practice by a reduction of superelevation on curved track, bringing with it the necessity for string lining curves regularly.

The second chapter describes in great detail the operations required to maintain the track to a high standard, with particular attention to Safety First in the proper use of tools. It is probable that Engineers and Inspectors, in these days when job analysis is necessary, may disagree with some of the methods, but they may well consider whether their practices in particular circumstances may not be improved after a comparison.

In the third chapter the organisation of Relaying or Renewal of track precedes the organisation of Laying. The mileage of new construction has shrunk to a small figure and, indeed, many miles have been abandoned owing to the competition of other forms of transport.

The fourth chapter deals with Points and Crossings to the extent to which an Inspector should understand this important subject. The Theory has been much simplified. It

is shown that Cole's Method is a particular case of the usual method by which the turnout curve is made tangential to the switch and the crossing. The cross-distance is not often or necessarily the track gauge, the springing or origin of the curve being offset from the gauge line. A French development which continues the curve beyond the nose of the crossing will be found of interest. Wholly curved tongues as used on the Great Western Railway and in France are described

Other mathematical calculations are collected in the fifth chapter including those necessary for string lining and for other problems connected with curves, and with points and crossings. At the same time practical considerations are given full weight. One major error has been corrected. The track gauge formerly taken in certain calculations should have been the centre to centre distance of rails.

Some of the new matter has been derived from discussions with fellow members of the "Permanent Way Institution" at meetings and conventions. Special thanks are due to Mr. Raymond Carpmael, Chief Engineer of the Great Western Railway, to Messrs. Rendel, Palmer and Tritton, for recent Indian practice, to Messrs. Livesey and Henderson, for Argentine practice, to Mr. Foxley, of the Crown Agents for the Colonies for Colonial practice, and to other friends and correspondents who have kindly criticised or have supplied information.

GORDON HEARN.

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CHAPTER I

STANDARDS OF TRACK

1.—Definition of Permanent Way.

THE permanent way (Fig 1) consists of rails, fastenings and sleepers, bedded in ballast, to be distinguished from the temporary lines laid down during construction for the carriage of materials, etc., above formation level.

The standards of permanent way are being subjected to the closest study in every detail, owing to the demand for higher speed with heavier loads. The strain induced in the track is very great, so that the materials used and the maintenance of the track both require to be of the highest standard. Economy demands that wear should be resisted, so that rough and ready methods of maintenance are no longer adequate. It may be said generally that the standard of Permanent Way lags behind increases in axle loads and speed.

2.—Gauge and Structural Dimensions.

The normal gauge of the track is the distance between the running edges of the two rails on the straight, for it may be widened on curves. Many different gauges have been adopted. Many " battles " have been fought over the relative advantages, and possibly countries now committed to a narrow gauge would prefer to have railways on a broader gauge, while other countries suffer from breaks of gauge. The first cost has usually been the determining factor, but some countries have converted a wide gauge to a narrower gauge on account of the cost of extensions into more difficult country

and the desire to avoid duplication. The gauges (but by no means all) and the highest standards adopted in many countries are detailed in Arts. 16 to 20. It is not likely that extensive conversions of gauge will now be undertaken.

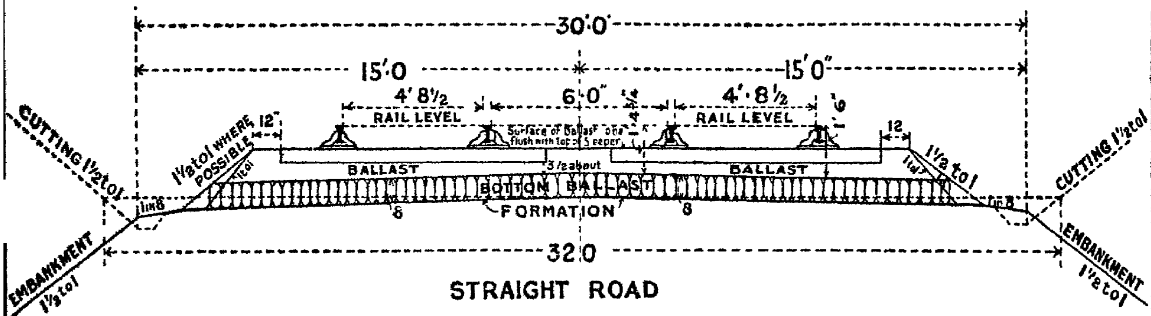
The broader gauges are usually the older gauges but they have been hampered by want of foresight in fixing the Structural Dimensions (such as Appendix A), to which the Permanent Way Inspector must continually pay great attention, in slewing and lifting the track. This is particularly necessary on curves, owing to overhang. At times specially wide loads may be carried and he should be aware of any spots at which trouble is to be apprehended. On some railways special vehicles are run over all the running lines, with frames and wooden fingers which will be broken off by contact with those obstructions, which encroach on the limit of Structural Dimensions.

3.—Iron and Steel.

It is desirable to have a working knowledge of the materials used in components of track in order to appreciate why they are adopted, and also what weaknesses to look for in maintenance of track, whether they are due to difficulties in design, or to manufacturing processes.

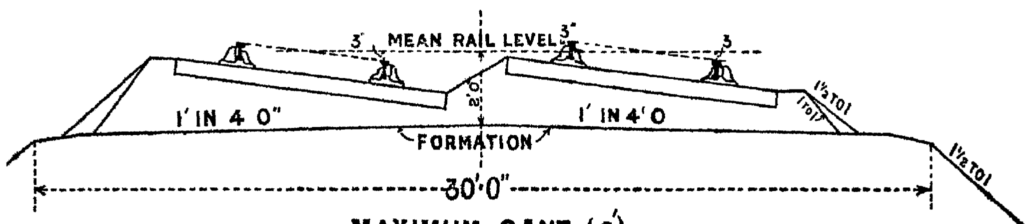
Iron is found in combination with chemical components, the least harmful of which is oxygen, which produces rust (iron oxide), while sulphur and phosphorus may be very harmful. A blast furnace is used to smelt the ore and the molten iron is tapped and run into trenches in a sand-bed, or machine cast, as "pigs." The product (it may almost be termed a bye-product, for many other substances are collected) is graded. It may be re-melted and mixed for castings, usually chilled for railway purposes, or may be converted into steel. Cast iron can bear only a limited stress in tension and requires greater thickness, which adds to the weight, but it is not so liable to rust and to lose scrap value.

STANDARD FORMATION FOR PLATELAYERS



STRAIGHT ROAD

FIG. I



MAXIMUM CANT (6")

Wrought iron, with only 0·1 to 0·2 per cent. of carbon, is made by puddling. Rails of this material may still be found, but it is little used for permanent way materials now, being replaced by mild steel, with 0·3 to 0·4 per cent. of carbon.

Steel was produced by the Bessemer process in 1856, by blowing a hot blast of air through a converter charged with molten pig-iron and no scrap steel. It is a quick process, an 18-ton converter producing 50 tons an hour. The original process used an acid lining, but, in 1879, basic material was used, in the process of Thomas and Gilchrist. The acid process is regarded by British engineers as more certain, and as producing the hardest rail with equal carbon content and with less liability to flow of metal than open-hearth steel. On the Continent, the basic process is generally used and the rails are considered satisfactory.

The open-hearth process was introduced in 1868, to utilise wrought-iron scrap, after the Siemens regenerative furnace was devised in 1861. It was modified later by Martin, and now steel scrap is used. Tilting furnaces are used, and these may contain 250-300 tons of charge. The linings again are either acid, or basic (1888). Analyses have to be made but research has shortened the time required. Electric furnaces are used on a smaller scale, the largest furnace in 1936 having a capacity of 30 tons only. In all these processes the molten steel is poured into moulds to cool as ingots.

If a rail, and certain other components of track, be examined, there will be found the letters B.A., B.B., O.A., or O.B., indicating respectively Bessemer Acid and Basic, Open-hearth Acid and Basic. Most British rails are B.A. or O.B., although O.B. is not so hard as O.A. The month and year of rolling, the weight per yard and the manufacturers' mark, will also be found on the web of a rail.

Increased carbon content increases the tensile strength of steel up to 0·9 per cent., when steel becomes brittle, the ductility, as shown by elongation under tension in a testing

machine, steadily being reduced. Addition of manganese and silicon increases toughness and resistance to wear. A medium manganese steel may contain 1·70 per cent., and high manganese steel as much as 20 per cent., but this is usually cast. The addition of rarer elements appears unjustified. Chromium in mild steel reduces corrosion, and so does copper, an expensive element at present prices. All alloy steel is improved by heat treatment, designed to distribute the elements evenly, or by controlled cooling.

For other components of track, absence of exposure to abrasion demands a different composition to that of rails. Fishplates and bolts must have a high tensile strength with more elongation, while steel sleepers are made of a very mild steel. This is very liable to rust, except in a very dry climate, where perhaps salts in the soil have a much worse effect. An addition of copper, say 0·5 per cent., reduces this tendency by perhaps 25 per cent., except in tunnels, also where rails are exposed to dripping of brine from refrigerator cars. It is probably more effective to spray the web and the base of the rail with oil containing an asphalt base.

4.—Rails.

The following terms will be used in descriptions of the section of a rail:

The *Table* is the top surface of the *Head,* which is rounded off at the edges, and curved on the top.

The *Face* is the vertical side of the head.

The *Web* connects the head to the *Foot* or *Bottom,* that is, the lower flange. In B.S.I. flat-bottomed types the web is battered.

The *Fishing Planes* are the sloping surfaces from the face to the web and to the top surface of the foot, differing in B.S.I. types.

The composition of the rail steel is the province of the metallurgist in consultation with the manufacturer, who is

responsible for the rolling, but the Chief Engineer will be guided by reports from the Permanent Way staff on the behaviour of the rails in the road. High tensile strength is required, from 44 to 52 tons per sq. in. with an elongation of 10 to 12 per cent., and a working stress of 14 tons per sq. in.

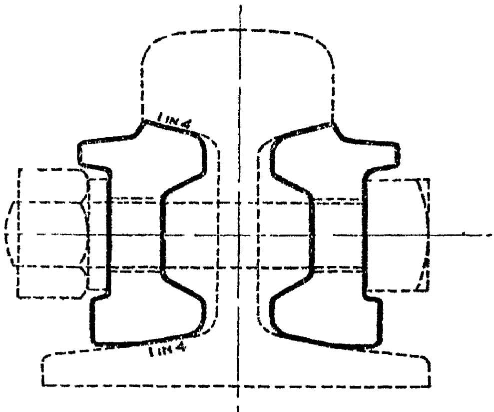
A modern steel rail is a continuous girder, supported by the sleepers, and is designed to resist tensional stress in the foot and compressive stress in the head. Hardness to resist abrasion and wear must be a very important factor, provided that the other two factors are not unduly reduced.

The Bull-headed rail (1858) has displaced the D.H. It is rather flexible laterally, but the strong lateral support given by the broad-based cast-iron chairs is of great advantage in sustaining the shock and vibration of modern axle-loads and high speeds. The head contains more metal than is required for compressive stress, see Report 9/1935 of the B.S.I. and Table I. Continental engineers admit that a B.H. rail (Fig. 5) is ideal, but the cost is too high for them.

In 1836, Vignoles designed the flanged or flat-bottomed, or flat-footed rail (Fig. 2), which is in general use all over the world, even where speeds are high and axle-loads heavy in the United States. It can be supported direct on wooden sleepers, but, unless they are of hardwood, a bearing plate is used to distribute the load over the fibres of the timber. The spike fastenings are apt to work loose, until sometimes they may be picked out with the fingers. Since high speeds necessitate an increase of speed on curves, it is a serious problem whether fastenings to F.B. rails will continue to be adequate to resist side pressure. On the straight also, locomotives have a tendency to "hunt" or "nose" along from side to side, causing side pressure. Figures taken from Report 11/1936 of the British Standards Institution will be found in Table II. It will be noticed in Fig. 2 that the web is battered inwards.

The F.B. rail is less flexible laterally than a B.H. rail.

The head contains less metal, in proportion of total weight, to that of a B.H. rail. In order to obtain equal sections in the head a B.S.I. 110 lb. F.B. rail is matched with a 95 lb. B.H. rail on experimental lengths of the L.M.S. Assuming that equal wear of the head will condemn in both cases, much more weight will be scrapped in the F.B. rail while the cast iron chairs of a B.H. track can be utilised again or a large pro-



FISHPLATES FOR F. B. RAILS

Fig. 2.

portion can be remelted and recast. The foot of the F.B. rail is wide, usually nearly as wide as the height, so that it may be laid on wooden sleepers direct with greater bearing area, but the foot could be reduced in width considerably, with a rather greater Moment of Inertia, for laying on cast iron chairs, bearing plates or steel sleepers.

The Moment of Inertia of a rail is the sum of all the areas in the section multiplied by the square of the distance of each area from the neutral axis of the section. The section modulus is this Moment divided by the distance from the top of the rail head to the neutral axis, and therefore is in cubic inches (Table II).

An alteration to the usual section was made in the Head Free Rail. The lower corners of the head were cut away, and the metal thus saved was added to the top table, making the whole rail stiffer, and able to stand more abrasion. Abrasion on sharp curves was found to be less, but the rail appears to have gone out of production.

Both the length and the weight of rails may be affected by manufacturing considerations The steel from the furnace is cast into ingots to cool until it solidifies. The dimensions of the ingot depend on the total weight of the rail. During cooling various impurities come to the surface, and the top third is usually considered to be less sound. The ingot is reduced in section in a " blooming " roll, cropped at both ends, more being taken from the top, and cut into workable lengths or " blooms," the top one of which is longer to allow for a test piece after rolling. Each bloom may make about three rails. One hundred and eighty feet of 100 lb. rails can be obtained from a 3-ton ingot, or eight 39-ft. 100 lb rails from a 6-ton ingot.

The bloom is passed slowly forwards and backwards through a series of rolls, which reduce the section gradually. The number of passes should depend on the time in which the rail piece cools to a temperature below which no tendency to develop a coarse grain will persist. If the head crushes under traffic, insufficient rolling will be indicated. Nowadays not nearly the amount of rolling is put into the work done on the rail as in the past. The finishing roll turns out the final section, and at the same time stamps on the web in raised letters the information mentioned in Art. 3. The top end of the ingot has been carefully watched throughout the process, and a discard is taken from the leading rail piece. In addition the rail which has been made from adjacent metal is marked with a star. Some railways demand that each rail length shall be marked in alphabetical order, an A rail being considered to be less reliable. A heavy section of rail will

contain a larger proportion of A or starred rails, and may receive less rolling. The discard from that rail piece which came from the top part of the ingot must include a five-feet length to be submitted to the tup test. Not less than $9\frac{1}{4}$ per cent. of the ingot weight is specified for crops and discards.

The cost of a set of rolls is high, about £3,000, while the cost of setting them up and of storage must also be taken into account. After rolling a certain number of tons the rolls have to be refaced. It is desirable that a set of rolls may be just worn out in complying with an order.

The rails, while hot, are laid on hot benches. Uneven cooling of the rail section, more apparent in F.B than in B.H. rails, causes them to become cambered. In straightening, when the rails are cold, a set of rollers is preferable, because local pressure in a "gagging" machine may set up stresses, a point to remember if using a "jim-crow." The ends are preferably machined to disclose piping in the rails. Contracts admit of a certain proportion of short rails, cut from those defective at the ends only. Generally these are three or six feet short, but for laying on curves some railways accept rails three inches short. No tolerance should be allowed in the rail section at the ends if they are to join properly, but elsewhere may be $\frac{1}{32}$ inch. The fishbolt holes may have a tolerance of $\frac{1}{32}$ in. in size and position. They are better drilled than punched. Rails for use in manufacturing points and crossings are specially inspected and marked.

The "starred" rail is marked with one star on the machined end of the leading end and with another on the side of the head near that end. Arrows are stamped on the web by the finishing roll, and in double track the rail should be laid in the direction indicated, so that the starred end shall be on the taking-off side of the joint. They should not be used on curves, or for points and crossings. Similarly circles are marked on the side of the rail which came from metal nearest the bottom of the ingot.

The ordinary method of production described may be varied by some method of heat treatment. The head can be quenched in water. In the Sandberg process the head is treated, while still hot, by a water spray blown on it and afterwards cold dry air. Thus sorbite, to a depth of ¾ in. in the head, is developed in the steel structure with increased tensile strength. Another Sandberg process is controlled cooling, with or without "sorbitising," particularly valuable in higher carbon steel.

Rail ends may be treated to reduce batter, either in the track or in the mill, since batter may begin before hardening gangs can get to work. The rail ends are reheated and the ends quenched. The heat in the rest of the rail causes the toughness to merge into softer steel. There is also an annealing process, reheating the rails and replacing them on the banks to cool. This is called "normalising" and it reduces internal stresses due to the rolling. Heat-treated rails show superior resistance to fatigue tests.

Chemical and physical tests for rails are given in Reports of the British Standards Institution already referred to. They vary for different processes of steel manufacture. The most important physical test is considered to be the behaviour under a falling "tup" on the head of the 5 ft. piece cut from the top end discard. If this fails, the starred rail is subjected to the test, and, if that fails, all rails made from the heat are rejected. The test piece is supported on a specified anvil, head upwards. In order, however, to disclose a rolling defect of a "lap" or fold in the steel structure at the junction of the web and foot of F.B. rails, a pendulum weight is swung against the lower edge of the side of the head of a 2 in. length with the foot clamped down. This test may not disclose all the "laps," and failure may occur during unloading over the sides of wagons. On the Continent of Europe a bending test is preferred to the tup test.

In principle, the longer the rail the better, because the

number of joints per mile is reduced. If the rails have to be shipped overseas, and handled by relatively weak labour, or if the weight per yard is great, a moderate length is preferred. The lengths are always in yards or metres. Some details are given in Art. 16 to 20.

The rail weight to be adopted depends on many factors. The stiffness, strength and durability are all to some extent dependent on the number of sleepers laid to a length, on the nature of ballast, on the amount and weight of axle-loads passing in a given time, and of the speeds of operation One railway in the United States, after a study of all these conditions, arrived at a section which weighs 137 lb. per yard. For speeds up to 50 m.p.h. five pounds per yard per ton of axle-load is on the safe side, if the sleepers (N) in a rail length number not less than the number of yards plus one. For speeds of 60 m.p.h., and over, and rails weighing over 100 lb., four pounds per ton per yard of axle load will suffice if the number of sleepers is N+4. No rule can absolve from endeavouring to keep the track up to a high standard, and, if all endeavour fails, to draw attention to the fact, or to impose a restriction of speed.

The weight of rails in tons per mile is approximately equal to the weight in lb. per yard multiplied by 11/7. A small addition is made for cutting rails and for imprest stock.

5.—Check and Third Rails

Check rails are held to the inner rail of a sharp curve, or to the rail opposite the nose of a crossing, and sometimes have to be used if the turnout curve is sharp. They are a precaution against derailment and also reduce the wear on the outer rail of a curve. They should commence and end 50 ft. beyond each end of the curve. They must allow the wheel flanges of a long rigid locomotive wheelbase to pass between the check rail and the inner rail. The table of the rail should stand slightly higher than that of the inner rail.

The wear on the check rail will be entirely on the side of the head, and the width of table can be reduced. The advance of the joints of the check rail on a curve must be taken into consideration, and they are better staggered so that joints do not come opposite the joints in either outer or inner rails. This may require revision of the sleeper spacing. The G.W.R. of England uses check rails on curves of less than 660 ft. radius. On the broad gauge in India the limit is 716 ft., and 409 ft. on the metre gauge.

The B.H. chairs must be double (70 lb in weight) to carry the check rail, and in British practice no tilt is given to the check rail. In F.B. track the width of the rail foot is often greater than the width of head plus the clearance allowed, and a specially rolled section of rail may be required, or the foot of the check rail has to be planed. If the check rail is held to the inner rail by distance pieces and bolts through holes drilled in the webs of both check and inner rails, the spiking to wooden sleepers may be done inside the check rail and outside the inner rail to which it is attached, but, if bearing plates are used, they must be specially wide. Special cast-iron and steel sleepers must be devised to carry the check rail. Clamps also are used to connect the two rails at intervals about 8 in. apart, after the inner rail has been fastened down on a bearing plate.

Third rails are used to conduct the current to be picked up by contact shoes. They are of F.B. section up to 150 lb. per yard, and are carried on insulators several sleepers apart. Between stations they are bare and introduce special problems in track maintenance. Within station limits they may be guarded by wooden boards on both sides. The rails should be of very mild steel, and as near pure iron as possible.

Guard rails of I or channel section at level crossings can be held to the running rail by clamps similar to those used with check rails, or by brackets, or by distance pieces with bolts through both rails.

6.—Rail Joints.

The rail joint (Fig. 2) has to fulfil two requirements, as far as possible. It should be as strong as the rail, and it must permit of expansion and contraction of the rails (see Art. 28). There are two general types; the suspended, which depends on the fishplates for their strength, and the supported, by using a plate across the joint sleepers under the rail, or a sleeper directly under the joint. Some suspended joints have a strength only 30 per cent. of that of the rail.

The behaviour of fishplates under a rolling load across the joint space deserves examination. As the load reaches the sleeper space before the joint sleeper, the rail, as a continuous girder, must bend and raise the end at the joint. The receiving rail is under no load, but the end is raised by the fishplates, which assume a slightly convex shape (top in tension on the receiving side). Just as the load reaches the gap at the joint, the taking-off rail, acting as a cantilever, is bent down, and the plates assume a concave shape (top in compression on the taking-off side). The receiving rail is still under no load and tends to keep up, thus receiving a blow on (or near, if plates are new) the end of the table. This blow can be heard and the speed can be determined by the number of blows heard in a minute. As the load runs on to the receiving rail the end of that rail becomes a cantilever, and the taking-off rail is relieved, although, under a very short bogie, the end may be again bent up. The fishplates are still concave (top in compression on the receiving side). When a single load reaches the sleeper space beyond the joint space, the plates become convex (top in tension on the taking-off side). These will be the shapes assumed if the road is well packed and there is no "dancing" of the sleepers.

If, however, the joint sleeper on the receiving side is not packed or insufficiently drained, the effective joint span extends to the second sleeper from the joint. The taking-off

rail will bend more as a cantilever, and stresses will be higher. The top of the fishplates will be partly in tension and partly in compression until the load reaches the sleeper beyond the joint sleeper, but the point of reversal moves from the near to the far side of the gap in the rails. If both joint sleepers are insufficiently packed, the fishplates are concave throughout, the top being in compression on the taking-off side, until the receiving rail is loaded. Should both sleepers next to the joint sleepers be insufficiently packed, the fishplates will be first convex, then concave, and then again convex.

There will also be a transverse movement of the plates. When the load is directly over the joint the lower part of the fishplate moves towards the web of the rail and the upper part of the plate away from the web. When the load is on one side or other of the joint a reverse action takes place. Thus there is abrasion along the fishing planes and eventually the bolts become loose. Finally, one fishplate may be drawn, by tightening the bolts, into contact with the web and loses its effectiveness. This must be watched. If one bolt is tightened, it may cause others to become loose, and therefore all should be tightened, but contact between a bolt and the fishplate may damage the thread and make tightening impossible. This may be remedied by using a longer bolt with a spring washer which will not damage the thread. Spring washers, spring cover-strips, or lock-nuts will not keep the bolts tight indefinitely. The washers should not be compressed completely.

A great deal of "working" occurs in a suspended joint. No tolerance is allowed in the fishplates, but they become worn about 6 in. from the centre on the receiving side and 3 in. on the taking-off side. The wear is greater on the taking-off side, and is at the top of the plate at both ends and at the bottom in the middle. The Pennsylvania Railway planes off $\frac{1}{16}$ in. at these three points, introducing springs. Fracture in a suspended joint may be expected to commence

by cracks from the top fishing plane downwards at the gap in the rails, where the metal of the fishplate may actually flow into the gap. The underside of the rail head also becomes worn near the rail ends, and the rail cuts into the top of the fishplate. The receiving rail end becomes battered and the metal flows. The reactions in the rail joint described above occur in double track. In single track, where the traffic passes in both directions, every rail end becomes a taking-off and receiving end.

Fishplates of the same section throughout their length can be rolled similarly to rails, sheared and drilled. The rolls require frequent dressing. Plates which are swelled out at the middle, or are otherwise of unsymmetrical section longitudinally, must be drop-stamped or pressed in a coining press. Drop stamping is used in giving a camber to worn plates before replacement.

Steel for fishplates in a suspended joint must have toughness and ductility. Heat treatment and quenching in oil improves the first quality, but it reduces the elongation. It reduces the tendency of fishplates to develop cracks. The B.S.I. Report No. 47/1928 specifies two classes of steel, the limits of tensile strength being 28 to 42 tons, with elongations of from 20 to 22 per cent. A Class A flanged fishplate for F.B. rails must have the flange sheared off and be then bent cold through 180 deg. while the flange must stand being bent upwards through 45 deg.

The specification for fishbolts and nuts is still No. 64/1913. The characteristics of the steel are nearly the same as for fishplates, and testpieces must be capable of being bent cold round a bar of equal diameter until the sides of the pieces are parallel without sign of fracture. Nuts are tested for resistance to unscrewing. Finished bolts and nuts are dipped into linseed oil. The tolerance in diameter is $\frac{1}{32}$ in. over, and $\frac{1}{64}$ in. under. It is unnecessary to submit bolts to a tension of over 20,000 lb. per sq. in., but heat-treated bolts can stand 26,000 lb.

A fine thread bolt is less liable to slacken by the "working" of the fishplates. Shorter spanners, however, must be used, otherwise there will be a risk of stripping the threads. Possibility of excessive shear stress should be taken into account in obtaining mechanical nut-screwing machines. Square nuts are perhaps easier than hexagonal nuts to engage with the spanner.

The design of a fishplate should take account of the wear of the rail table and the consequent lowering of the wheel flange into possible contact with some part of the plate, before the rail becomes condemned. Since rails will probably be used to the limit in sidings after replacement in running tracks, this is a point of importance.

The simplest form of fishplate in section is the one used on bull-headed track of British railways. It is normally 18 in. long, flat on one side but bevelled on the other, and this is the side to fit to the rails. The bevels are to the angle of the fishing planes on the under side of the head and the upper side of the foot, and the angle of intersection of these planes is usually 28 deg. The holes for fishbolts are made pear-shaped so that the bolts, with a similar shank, shall not turn while they are tightened.

The fishplate may be angular in section, thus providing more metal to resist tension, although the neutral axis is lowered. They are less likely to jam than those of symmetrical section as they tend to separate under the load. The turning of the bolt is prevented by a channel in the section. The height between inside edges of the bevels must be sufficient to prevent the inside of the plate touching the web of the rail, and thus restricting the expansion and contraction. Theoretically, the work done by temperature changes in a rail, free to expand, should be equated to the work done in overcoming friction between the rail and the fishplates at the fishing planes, and this will depend on the tension in the bolts. An angle fishplate should not be fitted upside down, or the

benefit of the additional metal in tension is lost It is impossible to do so with B S I., F B. rails, because the fishing planes have not the same inclination.

Long fishplates with six bolts were used at one time, but these had the effect of lengthening the span between sleepers at the joint, and of restricting expansion. In some cases the plates were slotted for spikes and carried at the ends on the joint sleepers, being in fact supported joints. For B H. rails, the latest design uses short two-bolt plates, only 9 in long, thus shortening the span at the joint with little resistance to expansion. The L M.S. uses these plates, except on curves over 2 deg., where 18 in. plates are used The chevron joint on the Midi section of the French National Railways has 8¾ in. plates cambered vertically, with contact along 3⅛ in. at the top and for 1½ in. at two places at the bottom, and with two bolts only. The joint span is 16 in. centre to centre of sleepers. A short span is desirable in every way.

In another design for a four-bolt joint, the plates are splayed outwards at the ends. The two outer bolts thus draw in the plate ends with a clamping effect, tending also to keep the nuts tight. One plate of a pair is cambered with greater thickness at the centre. In another design the outer plate is deeper and projects slightly above the head with gentle ramps, so that it may carry the outer part of the wheel tread and relieve the rail ends.

A scarfed (Brogden) joint has been revived, the end of the rail being curved like an S. This requires special machining of the ends.

To fish together rails of differing section, combination or compromise fishplates are used. These plates at one end have fishing planes and bolt holes to fit the heavier section of rail, while on the other end they fit the end of the lighter rail. Thus the bolt holes in the plate are at different levels and spacings. Since the width and depth of the rail tables

differ, there is a vertical end set in both plates and a horizontal set, which is greater in the outside plate. These plates are relatively weak and should be used only temporarily in main tracks or should receive special inspection.

To fit a combination fishplate the rule is to stand in the centre of the track facing the joint and to fit on the near side of the joint that plate of the pair which has the smaller horizontal "set," and will bring the two running edges into line, while fitting the two sections to be jointed. The deeper portion of this plate fits the heavier rail, but if the two rails do not differ much in section the distinction is not so easy.

The supported joint is the earliest form, with cast iron fishbelly short rails, and meets a demand for greater strength under heavy loads, while the fishing need only resist side stress and keep the rails in line. Joints have been designed which are claimed to be fully equal to the rail in strength, and to carry 50 ton axle loads at 100 m.p.h. They may be as long as 44 in. over three sleepers, or 28 in. over two, carried on longitudinal bearing plates. In Germany the joint may be carried on two wooden sleepers placed together, or, in steel sleeper track, on a special double joint sleeper. A rail-free cast iron pot or plate joint sleeper for Indian Railways is described in Art. 10. Supported joints require measures to restrict creep. On curves their use leads to some complication on account of the advance of the inner rail and the joints should be staggered, that is, placed about the centre of each alternate rail.

Rails of standard length have been welded together into considerable lengths. Considerable quantities of good ballast are used, extending to 2 ft. beyond the ends of the sleepers, and 2 ft. in depth at the ends. The sleepers are mechanically packed, and special attention is paid to drainage. No trouble with "creep" has been experienced.

On electrified track, insulation with fibre or whalebone requires that ¼ in. or more shall be taken from the edge of

the fishplate, where it butts against the under side of the rail head and the top of the foot. Rail bonds are inserted in holes drilled in the rails on either side of the joint. Alternatively, copper wire may be welded to the rails. If any repairs are likely to affect the insulation or bonding, the Signal Department must be warned.

7.—Sleepers.

Longitudinal sleepers are practically obsolete, except along ashpits and inspection pits. It is not economic in modern conditions to obtain scantlings of 12 to 14 in. by 7 in., with a minimum length of 22 ft , as used, with 60 lb. rails, on the Great Western of England by Brunel, with transoms at distances of 12 ft. Transverse sleepers are laid parallel on straights and, as far as possible, radial on curves. They are made of timber, soft and hard, of steel, or concrete, or may be articulated with elements of cast iron or concrete to carry the rails, the elements being held to gauge by steel or wrought iron ties. Probably wooden sleepers make the best road for high speeds, and cost less to maintain, but the supply is limited, and every care of them should be taken.

The number of sleepers to a "panel" must be limited by the minimum distance between the sleepers required to pack them properly. This distance is 10 in., but it is usual to space them wider apart, except near the joints where they are given a closer spacing. One sleeper a yard, with one or more additional to the panel to allow for joint spacing, may meet the stresses in the rail resulting from heavy trains running at high speeds, but may be insufficient to spread the load over a weak formation (Art. 13). One railway lays 24 to the 39 ft. lengths. In turnouts the normal spacing is reduced.

8.—Wooden Sleepers.

A wooden sleeper has many advantages. Reasonable in weight, it can be easily handled, its shape makes it pack well

for transportation, and when laid in new track it will support the load temporarily before it can be finally bedded, although this should be done as soon as possible, before the rail becomes deformed seriously. Even if metal sleepers are to be used at a later stage, it is advisable to lay wooden sleepers at first. They have considerable elasticity, a factor in smooth running, and the sides are adapted to anti-creep appliances, while the whole side, when bedded in the ballast, offers resistance to rail movement. The gauge can be widened on curves without any complication of design, although the grip on the fastenings steadily deteriorates. A new section of rail can be laid by re-adzing the seats and using a different bearing plate. On the other hand an untreated wooden sleeper is specially liable to physical decay and to crushing, or even breaking, under the rail seat, and its scrap value is small.

The sleeper should be laid with heartwood downwards. Sapwood decays in the ballast, and is more liable to damage with beater packing. If the sapwood is on the top it seasons and dries out, whereas the heartwood cracks radially. Once these cracks extend beyond the treated zone decay is admitted. The annual rings of a sleeper throw off the water, and arrest physical decay which extends from the exterior to the interior, until a treated shell only may remain.

The British Standards Institution Report 589/1935, classifies timber under softwoods and hardwoods, which are undoubtedly desirable under the much heavier loads now in use, but they take longer to grow and are subject to greater competition for other uses.

The cross section of wooden sleepers must to some extent depend on possible bending moment under a load, but if the rule, to pack only for a certain length under the rail, be strictly observed then they can only be subjected to compression at the rail seat and fail by decay or by deterioration of the holding power of the fastenings. Except on the narrow gauges, where the whole sleeper is packed, the portion between those

parts packed acts as a tie, and is, of course, much too strong, but it has another part to play, with the ends. The sleeper, especially if anchors are applied, has to take its share in resisting movement of the rails, and also to prevent lateral deformation of the track. If the sleepers are closely spaced, more than one carries load, and this must be taken into account. At rail-joints British practice increases the width of those on either side of the joint, but this is unusual elsewhere.

Bridge sleepers for use with open top girders are made exceptionally thick and are laid at closer intervals so that the wheel of a derailed vehicle may not drop too far. On the narrower gauges with smaller wheels they are spaced still closer A minimum thickness is prescribed to meet this contingency. They are held down to the plate girders by hookbolts and the length must take account of this.

Sleepers for use at turnouts become exceptionally long as the two tracks diverge, the longest being laid under the crossing. These sleepers also are exceptionally wide, and are consequently costly.

In view of short supply of timber, every inch which can be saved in the length of ordinary sleepers becomes of importance, provided that the risk of splitting from the spike-holes to the ends is avoided. Fifteen inches should be sufficient to prevent this, so that the minimum length should be the gauge plus twice the rail base plus 30 in. Narrow gauge sleepers have a longer length in proportion to gauge, but the supply is not so difficult because more sleepers can be cut from a younger tree. Theoretically, if the whole length is packed on narrow gauges, the lengths become 6 ft. 6 in. for 3 ft. 6 in. gauge, 6 ft. for the metre gauge, and 4 ft. 8 in. for the 2 ft. 6 in. gauge, in order to resist the bending moments.

The economic production of sleepers from the tree is improved by making the width in cross-section twice the depth. From a tree of 14 to 17 in. dia., two sleepers of 10 in. by 5 in.

section can be obtained, and from a tree of 29 to 30 in. dia., eight sleepers, allowing for shrinkage and for "saw kerf." When sawing for sleepers of different sections it may not always be possible to get symmetrical grain. If a sleeper be examined at the ends it will usually be found that the rings, which represent the annual growth of the tree, are in the form of an arch. It is considered the best practice to lay the sleeper with the innermost rings, the oldest heartwood, downwards. Those sleepers which do not show this formation must be studied with a view to discover which of the broad sides is composed of the hardest wood. If distribution can be arranged, it is better to use hardwood sleepers on the curves, and softer woods on the straights.

Of insect pests the termite (neither "white" nor "ant") is the worst in tropical countries. It works in galleries of mud which it brings up from near the water level. If the ballast is clean and has good interstices, the formation of the galleries is made difficult and vibration of traffic destroys them.

After wooden sleepers have been hewn or sawn, they should be air-seasoned in stacks formed in several ways, but no sleepers in any layer should touch one another. Seasoning in close cribs is not only slow, but may also encourage fungous growth near the bottom of the crib. This growth is induced by leaving sleepers lying about in the grass. Forest soil is alive with fungi. The crib stack should be open, be in the shade, and the lowest timbers should be raised about a foot above the ground on a base of gravel or cinders. It is better to use special cross timbers, painted with creosote, and burnt afterwards. The tops of the stacks should be covered, but not with thatch on account of fire risk, and the sides should be protected from drying winds. The seasoning should be gradual and even.

A comprehensive specification is as follows:

Sleepers should consist of thoroughly sound and seasoned

wood and be cut from the heart of sound trees, straight in fibre, one year before inspection. They should be free from bark, dry or wet rot (often due to lying on the ground) or wet sapwood, soft spongy or fungoidal or decayed matter, large or loose knots (particularly where the rail seat will rest) cup-shakes or bad cracks. They should be straight and not warped.

It is possible to interpret this so severely that a majority of those offered will be rejected. Longitudinal cracks certainly reduce the holding power of fastenings, but incipient cracks at the ends of seasoned sleepers are not so serious as in a green sleeper. If a S or Z iron is hammered on, after clamping the crack together, and the ends of the sleepers are painted with creosote in the stack, slight cracks are not likely to develop further. The iron should cross at right angles the greatest number possible of radial lines in the grain, but two may be required, one at the top and one at the bottom. Small cup shakes at the ends are not likely to develop further. The ends are apt to receive special attention by passing officers, who only then proceed to examine the broad sides for shakes, surface cracks, and knots, some of which are perhaps more important. In certain timbers a sure sign of deterioration in the track is a longitudinal groove, often containing small ballast.

There is no objection to acceptance of sleepers with a bevelled arris or "wane" on two corners, cut from a slightly smaller tree, so long as there is no sapwood left. In sal the sapwood is actually stronger than the heartwood. One method of impregnation is claimed to treat sapwood. The sleepers passed are marked with a brand, which should be jealously guarded from interested parties. The sleepers should then be stacked at once. No tolerance under the prescribed dimensions can be allowed, but a reasonable excess cannot be objected to.

Wooden sleepers are subject both to mechanical wear and

to physical decay, usually the greater cause for deterioration of untreated softwood sleepers. Preservation is very largely practised. The additional expense is fully covered by the longer life and the saving in labour of renewal. The importance of treating long and expensive crossing sleepers is not fully recognised. In Great Britain the practice of treating is universal for the imported Scandinavian and other softwoods, including Douglas Fir. It increases the strength of the timber.

Many methods of treatment with various salts have come and gone, but creosoting is the one most employed. The B.S.I. standard is No. 144. The Bethell Full Cell process (1838) is still used in Great Britain. The more creosote per cub. ft. is absorbed the lower is the percentage of removals in a given time. Freshly creosoted sleepers are slippery to handle. Gloves should be worn.

The Ruping Empty Cell process (1902) economises creosote. The Lowry process is similar. It is claimed that these two processes impregnate a sufficient amount, make them cleaner to handle, and avoid wastage, which in hot, dry climates may be very great.

The untreated sleeper may need conditioning, a gradual reduction of the moisture content, or otherwise it may split in areas of very low humidity. Some timbers, such as jarrah, imported by sea, absorb a quantity of moisture, and unless they are gradually air-conditioned they fail and give an unfavourable impression. It may be necessary to cover these sleepers with soil or ballast, for protection against evaporation by the sun, even after they have been laid. The penetration of the timber in creosoting is not deep, except at the ends, and therefore if any damage, such as a derailment, occurs, which may expose untreated timber, creosote should be painted over the wounds. It is the usual practice to adze and bore the sleeper before treatment, giving an increased life by about two years, but if these operations should have

to be carried out in the field the exposed surfaces should be treated with hot creosote.

Zinc chloride washes out if used alone, and is unsuitable for track circuiting. In the Card process it is mixed with creosote and tar. It seems to suit some timbers and is considerably cheaper than creosote alone.

"Powellising," a secret process, treats with saccharine and some poisons added. It is an open tank process, but the pores of the timber are said to be filled, so that fungoid growths and white ants cannot enter. Zinc meta-arsenate also has been used, by the Ruping process, and costs considerably less than creosote. It decreases conductivity.

When sleepers are laid in the track, dating nails should be driven in them, so that their behaviour can be watched and recorded. The dates can also be cut in untreated sleepers, making the dates more visible.

Hand adzing should always be done to a template. Adzing with the grain is difficult but avoids splinters. Saw cuts are made across the sleeper to the required depth on the inner side of the adzing. The width of the adze should be half the width of the sleeper, so that two cuts will be sufficient, but if the workman is unable to handle such a tool then a width of four inches is adequate. The tool is rather dangerous and must be kept sharp. Goggles and leggings should be worn. The thickness depends on whether new sleepers or old are to be treated, the adze being thinner in the first case. If the sleeper is to be re-adzed under the lifted rail, the length of the blade must be greater than the width of the foot of the rail, and must allow for sharpening.

All holes must be bored right through the sleeper with an auger of slightly less diameter than the size of the spike, which should fill the hole completely when driven. In hardwood the auger may be $\frac{1}{16}$ in. and in softwood $\frac{1}{8}$ in. smaller. The boring must be done to template. If the point will not hold a little oil should be used.

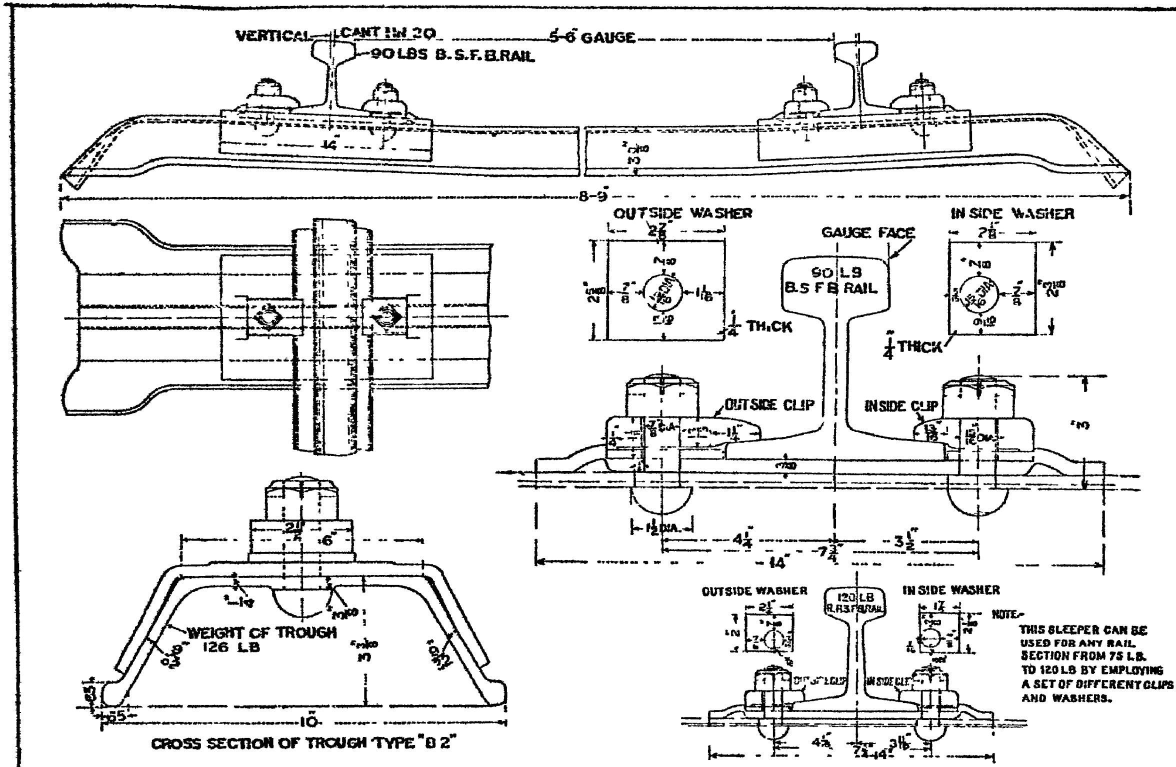
9.—Steel Sleepers.

Most Permanent Way men prefer a wooden sleeper track, but recourse to other materials is imperative. Steel, cast iron, and concrete are all better able to resist side pressure at the rail foot. Steel sleepers have great resistance to side pressure in the track, if properly bedded. It is imperative, however, and this applies also to cast iron bowls, to pay great attention to lining when laying. If this is done, steel sleepers may cost very little to maintain, if not, it will not be possible to get a first class road, and maintenance may cost half as much again as on a wooden sleeper track. In the Federated Malay States maintenance costs double. Lining becomes difficult because the sleepers tend to slide back into their old positions under traffic. If the first lining and bedding has been faultless, it is possible to maintain line by adjusting the fastenings only, provided that they are adjustable for side movement of the rails. A double key fastening on each side of the rail foot is preferable. The lining then can be done by two intelligent keymen without the necessity to disturb the bedding. Steel sleepers are not necessarily more noisy although running on metal sleepers seems rather "hard."

The bearing area of a steel sleeper may be taken as four times the distance from the centre of one rail to the end of the sleeper on the same side. These sleepers should not be allowed to become centre-bound, but on very narrow gauges this is practically impossible, so that the length approximates to twice the gauge plus the width of the rail head. The total bearing areas necessary under axle loads on Indian Railways were fixed by the Indian Track Sub-Committee (1926), as:

	5′ 6″	metre	2′ 6″	2′ 0″
Normal sq. ft.	5	3.33	2.25	1.75
Minimum	3.75	2.75	2.00	1.00

The minimum is for light rails and axleloads. The areas are not proportional, because the closer spacing of driving-axles on the narrower gauges was taken into account.



IMPROVED PEA-POD STEEL SLEEPER "COMPREHENSIVE" 1927 TYPE FOR RAILS FROM 75 LB. TO 120 LB.

Fig. 3.

A trough sleeper of inverted U section is easy to handle and to lay. It is not much more difficult to bed and is usually rolled in by a light locomotive, although in Germany and elsewhere the ballast is first moulded to template It is not difficult to pack if the ballast (½ in. to 1½ in.) is graded. Pebbles are unsatisfactory. More ballast is required if the same height above formation level is to be maintained, about 1 cub. ft. per ft. run, but this height can be lowered with the same amount of ballast below the bearing surface. The problem of their adaptability to track circuiting has not been solved, while in electrified track there is a risk of electrolysis, even with wooden sleepers. An addition of copper, while reducing rust, would increase conductivity.

The first steel sleeper in Great Britain for a B.H. rail to be used extensively, apart from an experiment on the G.E.R., in 1863, was patented by F. W. Webb in 1884. Other types of steel sleepers for British B.H. track are in use, the Great Western Railway having, altogether, half a million of several kinds over which speeds of 90 m.p.h. are attained, with 19 sleepers to the 45 ft. rail. All modern types are dished at the ends and have a beaded edge.

In F.B. track, steel sleepers have been used extensively in Germany and on the French Algerian railways. They were introduced into India in 1886. They are practically standard on railways under the control of the Crown Agents for the Colonies in Africa and elsewhere, and are used in the Union of South Africa. A type of steel sleeper is shown in Fig. 3, and this is adaptable to all F.B. rail sections by alteration of the clips and washers. Gauge adjustment is made in this type by turning the washers without removing them. The rail seat is strengthened by a saddle.

The simplest type of steel sleeper for F.B. rails is to use Mills' (silico-manganese) spring steel kidney-shaped loose jaws. These are inserted into drilled holes, steel keys hold the rail foot, and the weight of keying hammer should be limited to

4 lb. The K type, which is practically standard on railways under the Crown Agents for the Colonies, has holes through which a hammer-headed bolt is inserted and turned. There are two rail clips, one end of which is inserted into a hole while the other butts against the web. These clips differ in size so that $\frac{1}{4}$ in. or $\frac{1}{2}$ in. of widening of gauge is possible on curves. Then comes an over-riding clip secured by a nut on the hammer-headed bolt. The fastening is very secure and on the Gold Coast is reported as having arrested all creep. The G.E.O sleeper of German design for standard gauge F B. track has the bearing plate, described in Art. 12, welded to the plate. A double joint sleeper is used. Elsewhere a sleeper under the joint is not approved.

A steel sleeper with battered sides is not so suitable for the application of rail anchors, and therefore more reliance must be placed on the holding power of the fastenings.

Steel sleepers have been used for points and crossings and will prove more economical than costly timbers. Sleepers designed for right-handed turnouts can be turned end for end for use in left-handed turnouts. They can also be built up of old rails in pairs, tied and braced together with plates, riveted or welded on at the rail seats. The scrap value of such built-up sleepers is much higher than that of most sleepers. The depth of rail-section should correspond to that of wooden sleepers in such situations.

The higher first cost requires that a steel sleeper should have a long life. If only ten or twelve years should be the life of wooden sleepers, a steel sleeper with a life of 35 years ought to justify its use. Some steel sleepers in Germany required only 18 per cent. to be removed after 27 years. On the other hand sleepers weighing 148 lbs. lost 61 lbs. in four years in soil impregnated with saltpetre in Northern India. Rusting continues after sleepers have been removed from the track, thus continuously reducing their scrap value. They are not suitable in very humid conditions or near a sea coast. It

has been observed that sleepers rust more on the side towards approaching traffic, and so do those nearest the joints

Steel sleepers are made of mild steel, with a tensile strength of 26 to 33 tons per sq. in. and an elongation of over 20 per cent., but no precise composition or tests are specified in B.S.I. Report, No. 500/1933. The Bengal Nagpur Railway uses a bending test. Sleepers over weight, but not those under weight, are accepted. After acceptance they are cleaned of scale, and dipped hot into a suitable anti-rust composition, about 4 oz., usually three parts of pitch and coal tar to one part of tar oil. The coating should not be brittle when cold, or be affected by water, or by the heat of the sun. Any ridges on the top of steel sleepers collect water and grit and corrosion is started. The composition therefore may be applied at intervals to prolong the life, but this will entail special measures. It sustains damage from men walking along the centre of the track.

10.—Cast Iron Sleepers.

The cast iron bowl or pot was designed by Greaves. Indian Railways have a long experience of such sleepers, and still produce new designs, but they are not suitable to the high speeds which are becoming common. The material is comparatively cheap and easily cast. There is hardly any limit to the life of the cast iron components. They can be remelted and, after addition of a proportion of new metal, recast.

Cast iron has little tensile strength, compared with steel, and a transverse sleeper, wholly made of this material, would be of too great a weight. As it is, the total weight of an articulated pot sleeper is over 230 lb. A pair of elements, bowls or plates, including chairs or bearing plates, are connected by a tiebar of steel or wrought iron, passed through the cast iron elements and secured by gibs and cotters. The connecting bars are necessarily below the rail foot, do not add any strength against bending moments, and only tie

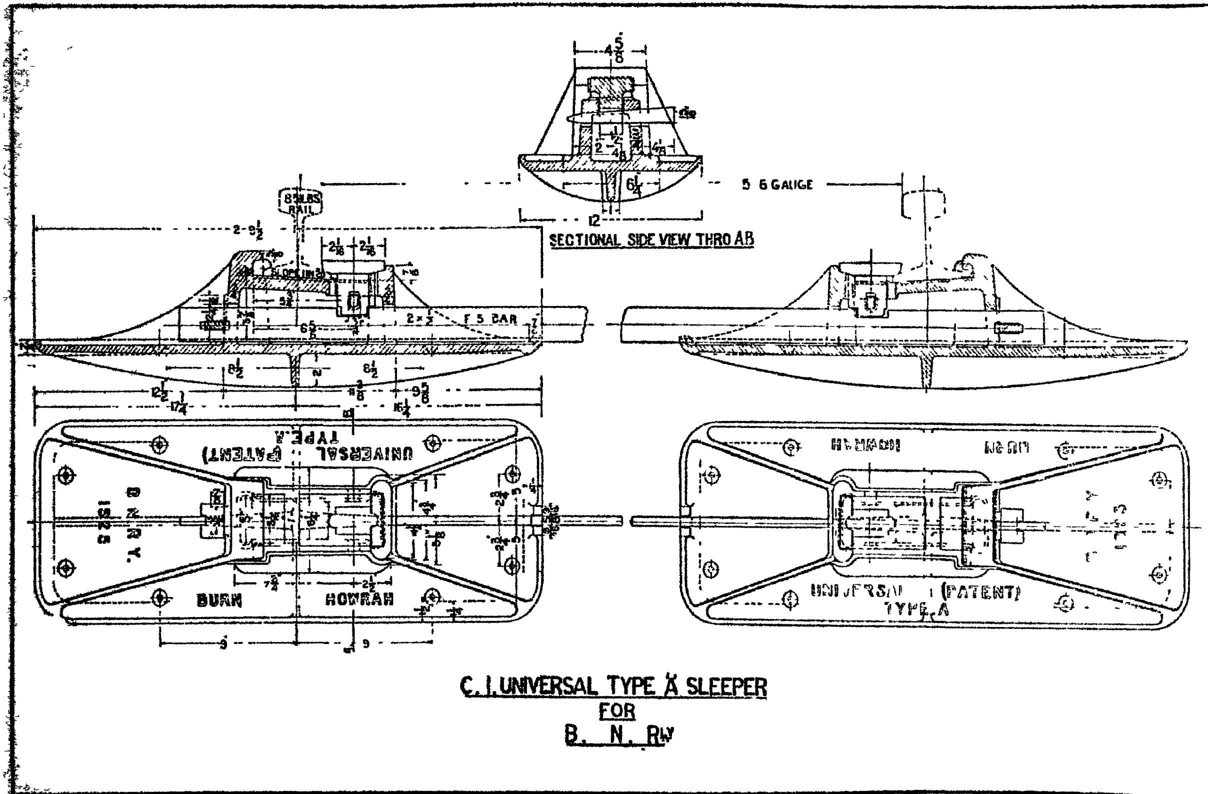

SECTIONAL SIDE VIEW THRO AB
5 6 GAUGE
85 LBS RAIL
2 × 2
F 5 BAR
UNIVERSAL (PATENT) TYPE A
BURN HOWRAH
B N R Y.
1925
C. I. UNIVERSAL TYPE A SLEEPER
FOR
B. N. RLY

Fig. 4.

the elements to gauge This can be widened without difficulty by exchanging the gibs and cotters, but, if the elements are tilted slightly, the gauge is not maintained. The longer axis of the element should be transverse to the track, and it can only give half the lateral resistance of a rigid sleeper. The rail seat should be narrow, otherwise a rocking action and creep of the rail must develop, and the span at suspended joints will be longer, so that the joints become hogged. When pots have become well filled, and this may be facilitated by "punning" ballast through holes in the pots, they have a good hold. On the G.I.P. Railway chaired pots are laid and keyed alternately right and left handed.

Plate sleepers are designed with fins, about 2 in. deep, longitudinal and transverse, for the same purpose. It is not easy to use anti-creep appliances with these types, or to hold the rail foot securely to reduce expansion and creep. The weight of each element in Fig. 4 is about 108 lb., and the total weight 243 lb. By the use of different clips the sleeper is adapted for use with different sections of rail. Many of the designs for this type of sleeper are complicated by provision for unevenness of casting and for widening on curves. This complication is found, to some extent, in all metal sleepers, although the proportion of curves on which any widening is required may be small.

A recent design of plate sleeper for the joints of 115 lb. F.B. rail in India is described as "Rail-Free," Duplex, because there is no key between rail and sleeper, which is laid longitudinally. Each element weighs 204 lb. and the total with tie bar, etc., weighs 417 lb. The sleepers on either side of the joint sleeper are also rail-free, weighing 230 lb., while the other sleepers, with an area of nearly 6 sq. ft., have an inside key. Another type has an area of 2½ sq. ft. with two keys and fins 1½ in. deep to prevent movement in the ballast. On one N.G. railway, hogged joints have been cured by inserting sleepers of the Rail Free type.

11.—Concrete Sleepers.

Concrete sleepers, if made to the same dimensions as wooden sleepers, are extremely heavy, and very liable to disintegrate by mechanical wear. They must have wooden blocks to take the fastenings, or wooden packings under the rail seat, and these work loose. They are more likely, being smooth-sided, to pump up and down in the ballast. Stent's concrete pots have been used to some considerable extent in India, and a new process has been devised, but is not in production yet.

A longitudinal concrete slab over a length of 390 ft., on the Pere Marquette, designed to arrive at a "Permanent Way," were laid in 1926, and modified in 1929. It is not likely that such a road will come into general use, because the cost (about 50 per cent more than first class track), is so high that, even if there is no outlay on maintenance at all, which has not been the case, it must last 72 years to justify the outlay. In 1931 rail batter was noticeable, and most of the joints were welded up. By 1938, many of the clips had become broken, and the gauge had widened. The type might prove economical in a few situations, such as railway termini, where a light type could be used at low speeds.

12.—Fastenings

Whether the rail is laid direct on the sleeper or on bearing plates or in chairs (Fig. 5), an inward tilt must be given to the rail on account of the coning of the wheels. This coning was given principally with the idea, not now tenable (Art. 15), that on curves all the outer wheels follow the outer rail into close contact with which they are pressed by centrifugal force. Therefore, it was argued, the outer wheels, if coned, would run with a larger diameter, and radially to the curve. Another impression, perhaps, was that wheel coning would make the vehicles run centrally on the straights. It has,

on the contrary, been observed that locomotives and bogies, with wheel treads coned at 1 in 20, have a tendency to wriggle, or "hunt," on straight track. Irregular bright marks on the rails should be noted and the cause diagnosed. Coning of wheels is not likely to be abandoned, and an experiment with a view to abandon the tilting of the rail, made by French railways in 1918, was unsuccessful. In the United States greater stresses were observed in untilted rails. Cant on curves causes a modification of the tilt to a vertical plane in both rails, and the inner rail may even have an outward tilt. It is a question whether cant should not be limited to $\frac{1}{20}$ gauge, and a corresponding speed limit imposed.

There is an advantage, not to be exaggerated, in having a small number of fastenings between rail and sleeper. A F.B. rail can be held to gauge and attached directly to a wooden sleeper by two fangbolts (probably the strongest fastening), or dogspikes or coach-screws to each rail, the sleeper being adzed to give the rail a seat. The bearing area on the sleeper is thus the width of the sleeper multiplied by the width of the rail foot, but, while this may give an area sufficient to prevent crushing of the fibres under the load, it has the disadvantage of causing a rocking motion of the sleeper, and mechanical wear, due to the sinuosity of the rail. The rail is rolled forward under the load and creep is greater. The sinuosity of the rail also tends to draw the fastening, and it is sometimes prescribed that the spike or screw shall not be driven home, but that there should be a space of $\frac{1}{4}$ in. between the head of the fastening and the foot of the rail to leave space for the wave in the rail. This leaves the rail free to move and creep is increased, while the spike is more liable to draw on curves. The Ruping elastic spike, made of $\frac{5}{8}$ in. spring steel with a gooseneck arc bearing on the rail foot, appears to meet this objection and to reduce creep. In the U.S.A. it is not used on more than every other sleeper with satisfactory results. It has been under test on the L.M.S. since 1936.

Where two spikes per rail are used, the outer and inner spikes should be in line (Fig. 6) On a double track, the outer spikes should be in advance of the inner spikes in the direction of the traffic. On single track, the outer spiking should be in advance for half the rail looking from either joint. Thus, if anchors are applied, on the side nearer the inner spikes, there will be no fear of slewing of the sleeper.

Dog spikes are chisel-pointed (Fig. 6), but a diamond-pointed spike is said to follow the bored hole better. It is most important that they shall be driven vertically, and not tapped over after the first blow or two. If not then vertical they should be drawn out and driven again.

The coachscrew has greater resistance to the draw of the sinuous rail, and greater lateral resistance, although insufficient to prevent widening of gauge on sharp curves. It probably reduces abrasion between the rail foot and the sleeper very considerably. It is more costly to buy and to drive (in the absence of a power machine) more susceptible to rusting, and the gauge cannot be corrected without drawing the screw, while the spike can be so hammered in the final stage as to give correct gauge. In laying rails direct on wooden sleepers it is better to allow $\frac{1}{4}$ in. slack gauge, as some crushing at the inner edge of the foot is almost inevitable. In order to prevent a coachscrew being driven as a spike to save trouble, a small point is formed in the centre of the head as a tell-tale.

It may be necessary to use three spikes or screws to fasten each rail on softwood sleepers, usually two outside and one inside, but two inside and one outside is claimed to be better practice. Four are usually used at the rail joint, and on curves with a radius of less than 1910 ft. On ordinary curves three fastenings per rail will be sufficient, two on the inside and one on the outside. This disposition will counteract the tendency to overturn the outer rail, by flange pressure, and the inner rail, partly owing to the tilt becoming negative by superelevation, and partly to the vertical load being greater

under loads running at lower speeds than that for which the curve is superelevated. Extra spiking on curves may be avoided by the use of steel tierods with shock absorbers, which, it is claimed, remove the necessity for periodical regauging. The "Standard" half chair gives outer support.

Dogspikes are made from steel with a tensile stress of 24 to 28 tons and an elongation of 15 per cent., while coachscrews (screw spikes) have a higher tensile strength and elongation.

Bearing plates may have a single or double shoulder. They are used to prevent or lessen the mechanical destruction of the sleeper, and must, therefore, have a larger bearing surface than the foot of the rail over the width of the sleeper. The Lehigh Railway uses a plate of 106 sq. in. in area. They give a truer tilt to the rail than a comparatively roughly adzed sleeper, and, once they have found their bearing, further crushing of the fibres is lessened. In some designs the base of the plate is corrugated or honeycombed, which reduces the stress thrown on the spikes by side movement, but requires special adzing otherwise they move before they have time to get a seating. They may be trapezoidal in plan, wider on the outside of the rail on curves, on the inside on straights, to resist cutting into the sleeper. It is especially important to avoid such cutting into creosoted sleepers. In Fig. 6 four spike holes are shown, but on the straight only two spikes may be driven. In high class track, the spikes are not given the double duty of holding both rail and bearing plate, but the plate is held to the sleeper by separate spikes or screws, thus reducing cutting and mechanical wear of the sleeper. On the Est Region of French National Railways, poplar packing pieces without a bearing plate are effective.

In order to reduce the rolling forward of the rail under load, and consequent creep, the bearing of steel on steel can be reduced. It has been found that on steel sleepers with a 5 in. bearing, creep is less than on wooden sleepers with a 10 in. bearing between rail and plate.

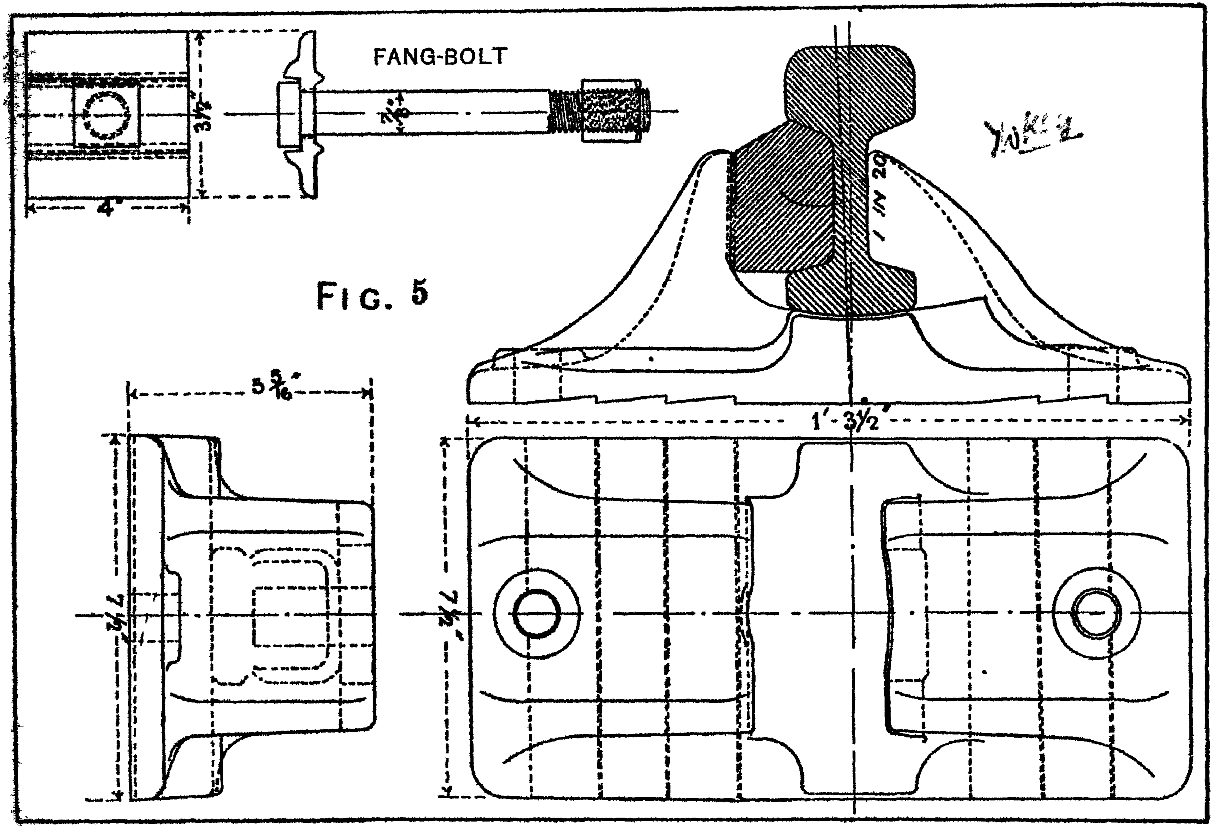
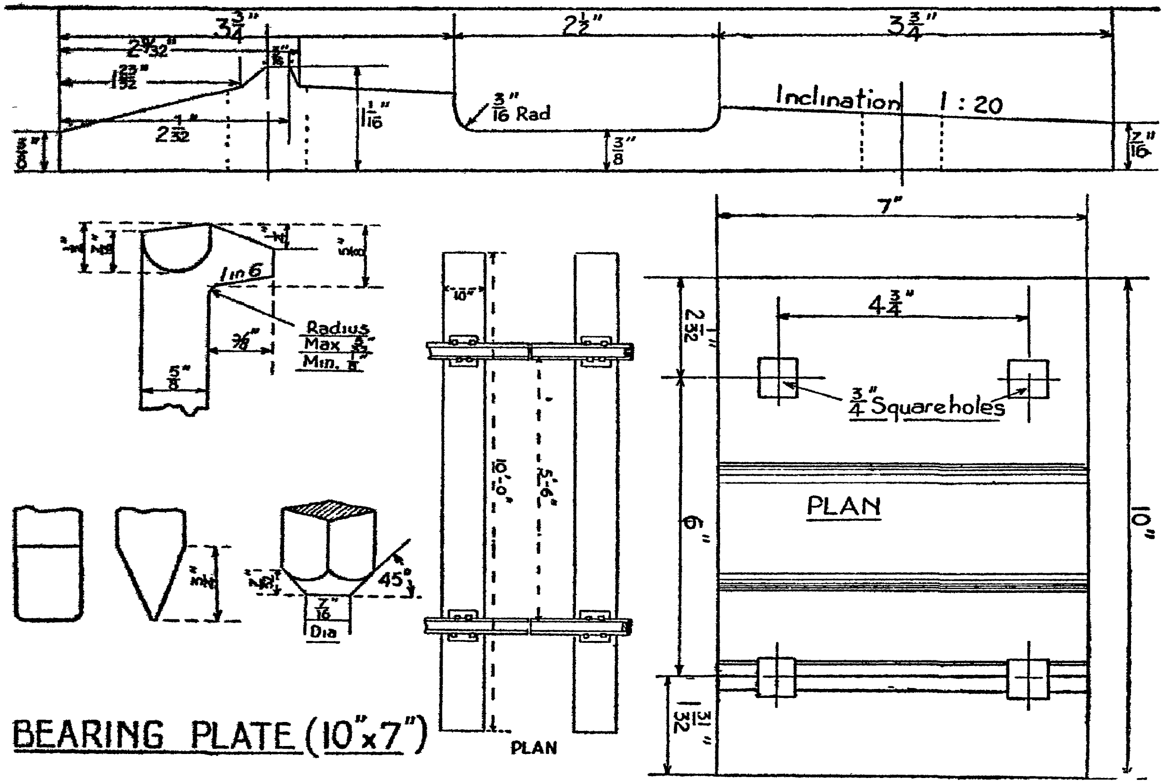


FIG. 5



Inclination 1 : 20
3/16" Rad
Radius Max 3/32" Min. 1/16"
1 in 6
3/4" Square holes
PLAN
PLAN
BEARING PLATE (10"x7")

Fig. 6.

The German type of steel bearing plate has a double shoulder to keep the foot of the rail in place with allowance of $\frac{1}{32}$ in. each side. The plate itself is secured to a wooden sleeper by four screw fastenings, and is welded to a steel sleeper. A wooden poplar packing may be inserted under the plate. The rail is fastened, independently, by clamps of U-shape through which bolts pass and are held tightly down by nuts. There are 22 parts for attachment to a wooden sleeper and 12 for steel sleepers. At suspended joints the bearing plate is carried over two sleepers with special wide plates and with either four or six clamps, and eight screw-spikes. If the joint is supported by a sleeper the plate overhangs it and the rail foot is held by two clamps on each side. The type holds the rail very well, and 98 ft. rails require a minimum of interval for expansion. It is costly, but over 6,000 miles of track have been laid in Germany.

Care must be taken in laying double shoulder bearing plates not to reverse them and get the wrong tilt, especially if the tilt is small. They are considered to hold the rail better against movement if the sleepers are slightly skewed, and, conversely, prevent serious skewing.

Bearing plates may be cut from rolled steel bars to bear a tensile stress of 24 to 32 tons per sq. in., or be drop-forged, or made in a coining press. Before bundling they are heated to the temperature of melting lead and dipped into boiled linseed oil. They are made also of cast iron, and are cheaper, although they weigh more. A good combination is a cast iron plate with elastic spikes, and this is cheaper with F.B. track than B.H. track with chairs, while equally effective on the L.M.S. experimental lengths. An Anti-Creep cast iron bearing plate has been designed for Indian Railways, with a bearing surface of 90 sq. in. The jaws have a double taper, enabling a two-way key to be driven in either direction to meet local creep conditions and prevent shoulder wear. One key may have to be driven at a joint before the fish-

plates are fixed. In all cases the longer dimension is transverse to the rail. An American double jawed design weighing 40 lb. for 110 F.B. rail has four screws, only two of which hold the rail foot.

The cast iron chair used with B.H. rails is a bearing plate. The Great Western Railway chair (Fig. 5) weighs 52 lb., with a serrated base area of 116 sq. in. It is applied to the wooden sleeper under a pressure of ten tons. This involves the adzing of the sleeper to a series of grooves. The chair is fastened by two through bolts, and the nuts are screwed by a machine to a constant torque. The G.I.P. Railway in India uses both right hand and left hand chairs alternately with the object of reducing creep. The joint keys must be driven always towards the joint, and the number of sleepers to a rail length must allow of this.

The keys, of hard close-grained wood, such as oak or teak, are straight or tapered, and are generally driven outside the rail, but they tend to shrink and to drop out, in which case the rail is devoid of support against lateral stress. Packing pieces or liners are used to take up wear. The keys may be treated with creosote. Steel keys, such as the Turplatt or Mills, require little attention, and are effective in arresting creep.

Rail anchors are not actual connections between sleeper and rail, but are sprung on to the foot of the rail and butt in pairs against the side of the sleeper. They should not be attached to the rail by a pin through a hole in the foot. This weakens the rail considerably, especially if movement requires new holes to be drilled. They should not slack off if the rail moves backwards, and be capable of being readily taken off and replaced. They provide that resistance to movement which dog or screw spikes cannot provide. Two-piece are perhaps better than one-piece anchors.

The proper points of application are on either side of the centre of the rail, as uniformly as possible, from the centre

outwards, so that expansion and contraction, although reduced, can take place equally in either direction. On a grade all should be applied on the uphill side of the sleepers. More anchors should be applied to the outer rail on a curve, than to the inner rail, which can be relieved by applying anchors to the check rail, if any.

Under very light traffic two to each rail may suffice, an extra anchor on one side being applied if movement is uneven. If the speed is high perhaps eight to each thirty feet length on each side may not prevent the slewing of the sleepers. In France five sleepers are connected by a steel St. Andrew's cross screwed to the sleepers. As many as twenty anchors have been applied to a 39 ft. rail in the U.S.A. Without rail anchors it is difficult, and may become impossible, to tighten the bolts at joints evenly or at all. The bolts may shear. On the Burma (metre gauge) Railway four anchors to a 36 ft. 60-lb. rail reduced creep from a foot a month to 5 in. a year.

If additional anchors are found necessary, they should be applied in hot weather while existing anchors are in full bearing. Otherwise the new ones take all the strain and perhaps shift the sleepers against which they are butted.

13.—Ballast.

Ballast has two functions. The loose material can be packed tight under the sleepers in order to maintain level and cross-level of the track. In addition it spreads the load on the sleeper over the formation. Some soils, when saturated, can bear only 15 cwt. on the square foot. The amount of spread of the load in stone ballast may be taken as one inch outwards for every two inches of depth under the sleeper. With dry earth ballast the spread will be wider, but the material is not so dependable. On a formation which cannot support a heavy load, therefore, the depth of ballast should be increased, but there is no object in having a greater depth

below the sleeper than the distance between two adjacent sleepers.

Bottom ballast, or soling, is useful to avoid the loss of stone ballast by sinkage and absorption into the formation, and also to spread an exceptional load due to depression of the track at a loosely packed sleeper. Bottom ballast should not consist merely of coarse ballast, but of small boulders, passing a nine-inch ring, and should be hand-packed. In the U.S.A. on a bad formation concrete slabs, 4 in. to 6 in. thick, have been used to distribute the load, with 8 in. of ballast over them. Concrete slabs have been used under diamond crossings.

A fruitful source of water-pockets in the formation is the provision of a small portion of ballast at an early stage. Depression under the rail seats and the packing both force the material into the formation. Water then drains through the second supply into the formation. It is better to pack with soil and consolidate before ballasting at all.

For lasting wear igneous rock, lime- and other stone, and slag are used. Igneous rock has much less binding value but the annual wear is smaller, about 3 per cent. Ballast should be hard, dense, tough and non-absorptive. It should break up into lumps and not flake in a crusher, as some limestone does. It should have good resistance to lateral displacement, and this resistance increases if the ballast is not being constantly disturbed. The coarser ballasts have a better capacity to carry heavy loads.

Slag is a waste product of the blast furnace, dug from the heap by mechanical excavators and sorted on a belt conveyor, so that the larger lumps can be sent to the crusher and the remainder pass to the screens. It tends to hold dust and dirt and is not suitable for use with steel sleepers for fear of corrosion.

The usual specification for ballast is that it should not pass more than a 2½ in. ring or less than a ¾ in. ring. For steel

and plate sleepers it is better to use a $1\frac{1}{2}$ in. ring or to grade it with a proportion of small stuff, not dust. The angle of friction must be studied or it may not be forced up into contact inside steel sleepers. On steep grades, where the locomotive scatters cinders over the track, the ballast should pass a $1\frac{1}{4}$ in. ring and still be retained on a $\frac{3}{4}$ in. ring.

There are other materials for use in second class track, since they have little resistance to lateral displacement. They tend to be absorbed in the formation and to form water pockets between the ridges. They are gravel, washed or screened or unscreened, mine tailings or chatts, broken brick or clay, muram (a red earth), kankar (a nodular lime), cinders or sand. The annual wastage is from 15 to 20 per cent. Sand must be oil-sprayed or blinded with stone. Some railways can afford nothing but soil, and the ballast section must be formed to a slope outwards, to below the bottom of the ends of the sleepers, so that water may drain to the sides. The slope must run to below the foot of the rail. The centre portion of the sleeper must never be allowed to become bound, and must be raked out during packing, which is done with wooden beaters. On very narrow gauges the full bearing area may be required.

For measured shovel packing (Art. 29), granite chippings are used. The material is kept in bins, spaced apart at every furlong, and filled periodically from a ballast train. The chippings are carried to site in a sack or box-barrow with handles at each end.

The laying of stone may well be deferred until the formation has had time to settle down, especially if the formation is of "black cotton," or clay, or other unreliable soils, which swell with moisture content. Sand should be laid to a depth of 1 ft. at first. In time such banks will drain out, or vegetation on the slopes will keep out the rain. A good depth of ballast and soling is essential to carry heavy loads at high speed. It will increase the "modulus of elasticity of rail support,"

save in maintenance, increase the life of other materials, and diminish track resistance. An additional depth of 6 in. of stone ballast, it has been calculated, at the cost of three additional sleepers per rail length, is more effective than the addition of six sleepers.

On curves, superelevation of the formation will reduce the depth of ballast under the outer rail. A considerable depth of ballast must increase the spread of the sideslopes and tend to reduce the "cess" or width of formation exposed, so that the width of formation may have to be increased. The formation width will depend also on the top width of the ballast section. Side ballast walls cannot be recommended. The cess must never be raised in regrading above the bottom of the ballast section or water pockets will be formed.

At one time it was the vogue to cover the sleepers, and even to make the section slope upwards from the centre almost to the bottom of the rail head. It is now considered better to leave the fastenings exposed, for grit is apt to work in under the bearing plates, in fact, less labour in repairs is involved if the ballast top lies an inch or two below sleeper level, and the running is quieter. Lateral movement of the sleepers is not increased appreciably. There is a slight risk of fire. Slag, or cinder ballast, if covering fastenings and the feet of the rails, inevitably causes corrosion. Although a wide shoulder is necessary to withstand lateral stress, it is not now considered necessary to allow more than about 8 in. of stone ballast outside the ends of the sleepers, but some railways still allow 12 in. on each side. A wider shoulder is desirable on the outside of curves. The ballast slope is taken as 1 in $1\frac{1}{2}$, but gravel lies at 1 in 2, and requires a wider shoulder.

For high speeds a smooth top to the ballast section is necessary, because if sleepers and ends protrude there is some drag on the train.

The ballast section is quite different if steel or cast iron

sleepers are used. The centre portion in a C.I. sleeper is left open, because ballast here serves no purpose and would only tend to corrode the tiebars. The extra quantity with steel sleepers is about 1 cub. ft. per ft. run for standard gauge. Sand should be filled into pots, but stone chippings are less liable to wash out.

14.—Stresses in Track.

A great deal of research has been carried out in the last ten years. It is not possible to give all the sources which may be consulted by the Permanent Way man. The Railway Research Service, 4, Cowley Street, London, S.W.1., can probably place the enquirer in possession of details of new components of Track.

Recent research shows the paramount importance of a stiff track, most carefully lined, and cross-levelled. It is much more profitable to improve the support than to increase the rail section, although the section may have to be increased on account of the intensity of rail stress, however stiff the support may be. Experiments in India indicate that the average "modulus of track elasticity" is greatest with cast iron plate sleepers, diminishing in turn for steel troughs, deodar and softwood sleepers, although the results differed widely in each group, with lateral resistance in the same order. The importance of cross levelling has been shown by one experiment of an American Committee, with a locomotive running at 70 m.p.h. Over a straight length of 45 ft., one rail was packed $\frac{5}{8}$ in. higher than the other, while on the adjoining lengths the cant was reversed. The lateral stress was raised from 7,000 lb., on track truly levelled, to 44,000 lb., considerably more than the load on any one wheel.

The load on the formation should vary as little as possible, otherwise water may collect in depressions under load. Pressure under the sleeper is very much higher under the centre compared with that at the sides, 160 to 1, and uniform

pressure is obtained only if the depth of ballast equals the sleeper spacing. Under a thin layer part of the formation between sleepers is unloaded, say one half when sleepers are 30 in. apart over 5 in. of ballast. The load is carried by several sleepers.

Sleepers in a rail length are spaced unevenly in order to space some closer near the joint. At certain critical speeds even spacing produces resonance and vertical oscillation. At a crawl, the joint will be depressed less with good ballast, but at high speed the movement of a wheel running on the continuous rail is actually less over yielding ballast until the critical speed is reached. Such a speed is almost unattainable with good ballast. The same good result is obtained by using a stiffer rail.

There is a certain amount of slip as a pair of wheels travels along the straight track. It is due to the strain in the rail and wheel surfaces in contact, probably oval in outline. There may also be a lateral slip. At high speed the coefficient of friction is reduced from $\frac{1}{7}$ to about $\frac{1}{18}$.

A pair of wheels fixed on an axle, even with cylindrical treads, oscillates along the rails in a regular curve. Coned treads cause the amplitude of the curve to increase. The flanges may impinge on the rails at intervals of about 60 ft. at 60 m.p.h. A Pacific locomotive has been found to oscillate laterally six times in a second. At low speeds the shocks will be slight, but at a spot half an inch out of alignment, with a cant of only a quarter of an inch there will be a severe jolt. The coning of treads has been reduced on the L.M.S. from $\frac{1}{20}$ to $\frac{1}{100}$, experiments with cylindrical treads having shown excessive wear of the treads. Bogies with independently rotating wheels have proved successful, but the cost is too high.

15.—Curved Track.

Curves introduce so many problems into practice that some

appreciation of the motion of a vehicle on a curve is desirable. A curve has the function of turning a train or a vehicle into a new direction at some angle to the direction in which it approached the curve. Centrifugal force would make the train continue in a straight line but for the reaction of the track, which rotates the vehicles, always running in straight lines, and transfers the vehicles to the far tangent point in a new direction. The curved track thus has to sustain an additional stress to what is imposed on straight track. Assuming that the same rate of speed is allowed on curves of different radii, linking tangents inclined at the same angle, the curve of shorter radius has a shorter length in which to complete the rotation of the vehicle, and therefore is subjected to greater stress per unit length. The rails show greater wear, the outer on the side, by reason of the friction of the wheel flanges, and the inner on the top, principally because all trains do not travel at the same speed, and the cant usually given for the fast trains is excessive for the slow trains, bringing a disproportionate amount of weight on the inner rail, which may develop a lip of metal which has flowed. A great deal of sliding must take place by rotation of the vehicle, and this takes place mostly on the inner rail. If worn rails on a curve are observed from above or from a little distance, the outer appears to be thin and the inner thick, sometimes exceptionally so. The same may be observed at worn points, one switch being thin and the opposite stock rail thick.

It has already been pointed out that there is a lateral oscillation on the straight. Assuming, however, that all wheel flanges have an equal clearance on entering a curve, the rotation of a bogie or vehicle will not begin until the leading flange makes contact with the outer rail, and then wear begins. The rotation may be considered to continue by a shouldering motion and by sliding owing to the action of a couple. This may be correct if the side springs, tending to centre the bogie pivot, have a tension of the order of one ton,

insufficient to have any effort in orienting the locomotive frame, which rotates by the action of the leading driving wheel flange. If the tension is from four to six tons, a more powerful couple is set up, and both bogie wheel flanges may be forced into contact with the outer rail. Unless the radius of the curve is such that the coned wheels will run radially, there will still be some slipping.

Experiments were made on the Est Section of the French National Railways in 1935 to determine the paths of the driving wheels of a 4-8-2 locomotive round a curve of 600 metres (1,969 ft.) in radius. The bogie springs had an initial tension of 4½ tons and a maximum of 6½ tons. At a crawl, the inner leading driving wheel flange was often in contact with the inner rail, with the second and third in continuous contact. As the speed increased, at above 50 m.p.h., the second and third inner driving wheel flanges in turn abandoned contact with the inner rail. At 62 m.p.h., the first and fourth driving axles guided the locomotive, the first in contact with the outer, and the fourth with the inner rail. At 75 m.p.h. the flanges of both first and fourth driver were in contact with the outer rail, the second and third making contact with neither rail. With a Pacific type locomotive on this curve, up to 68 m.p.h., the leading outer wheel flange guided, and no other flange was in contact with either rail. At the higher speeds the cant was in deficiency up to 3¾ in. by the usual formula, and this may have had some effect. The tracks of the bogie wheels were not recorded.

The reduction of cant is one of the important advances in practice of recent years. The formula in Art. 62 gives equal pressure or equilibrium on both rails, disregarding wind pressure, for all heights of the centre of gravity. The demand for high speed could not be met if speed must frequently be restricted, because the maximum cant of 6 in. or even 8 in. has been attained. The introduction of motor stream-lined trains with a low centre of gravity led to research.

So long as the resultant of centrifugal force, plus wind pressure from the centre of the curve, and vehicle weight does not fall outside the middle third of the gauge, centre to centre of rails, there should be no danger of overturning. In practice, the resultant is made to fall in the middle fourth, and a safe deficiency of cant may be taken as $\frac{1}{20}$ part of the gauge, centre to centre of rails. The A.R.E.A. adopt three inches although the centre of gravity of a locomotive may be 84 in. above the plane of the rails. On British Railways up to $3\frac{3}{4}$ in. may be allowed.

The reduction of cant, however, is contingent on very careful alignment, and keeping to the amount allowed for cant. Even newly laid track, apparently well aligned by eye, has differences in versine so great that the nominal radius is reduced in places by one sixth. On transition and easy circular curves small differences in versine have a greater effect. The cant does not then correspond to the curvature. Although small differences in cant have been found to make little difference in lateral oscillation, compared with irregular lining, the cant should be carefully maintained. If there should be a derailment, the first step taken in the ensuing enquiry will be to measure the cant and the curvature. On badly aligned track there is considerable oscillation between the rails.

Security against derailment decreases with an increase in the diameter of the directing wheel, with the angle of impingement, and the co-efficient of friction. On the other hand an increase in the horizontal angle of inclination of the exterior face of the flange contour is favourable. The value of this angle is limited by the wear of flange and rail and increased by curve resistance. Stresses on the inner rail may be as high as 60,000 lb. per sq. in.

Deficiency of cant will impose an additional thrust, besides that necessary to orientate the locomotive, on the outer rail. Dr. A. N. Talbot calculates this to be equal to the axle load,

multiplied by the deficiency of cant in inches, and divided by the distance centre to centre of rails, in inches also.

It is difficult to evolve a general formula for the authorisation of speeds in relation to curve-radius. In India, Martin's formula, as applied to all gauges, is :

$$V=1{\cdot}5\sqrt{(R-220)}$$

V being speed in m.p h , and R, radius in feet.

For curves of under 5°, V may be increased to $1{\cdot}35\sqrt{R}$, which may be compared with $1{\cdot}117\sqrt{R}$ by the equilibrium formula. The general formula obviously has limitations, because a curve on the narrow gauges may have a radius as low as 240 ft. or even 120 ft. If curves are not transitioned only $\frac{4}{5}$ V, as found, is allowed. The International Railway Congress at Cairo, in 1935, fixed a radius of 1,980 ft. as the limit for unrestricted speed on the standard gauge.

There has been a considerable reduction in gauge widening recently, although driving wheel bases are longer, see Art. 61. Experiments in India on curves of 1,273 ft. to 1,910 ft. radius on the broad gauge showed less resistance on normal gauge than if it were widened by $\frac{3}{8}$ in. to $\frac{3}{4}$ in., the wider having no effect. In the Est Railway experiments the Mountain locomotive, with a driving wheelbase of 20 ft., behaved much better with normal gauge on the 1,969 ft. radius. On British Railways widening starts when check railing is required, for a radius of 660 ft.

16.—Standard Gauge.

This is the usual name given to a gauge of 4 ft. 8½ in. to 1·435 to 1·445 metres. It emanated from Great Britain, but in the British Empire is not much used. It is the general gauge for Canada, the United States, and Mexico. In South America, some of the Argentine railways are laid to it, as are also the railways of Peru and Uruguay. In Australia it is the gauge of the New South Wales and Trans-Australian

railways only, other States of the Commonwealth having long ago adopted other gauges. In addition to other gauges, it is employed in China, South Manchuria and Japan. In North Africa, the Egyptian State railways, and French railways in Algeria, Morocco and Tunis use it, while it is to be found in Palestine and Iraq, besides the metre gauge.

The structure gauge in Great Britain is rather cramped, and some lines cannot accommodate any but special stock. The maximum width of stock, allowing for curves, is 8 ft. 10 in. with a height of 13 ft. The standard rail is 95 lb. B.H., 45 ft. long, but 120 ft. rails are used on the L.N.E.R., being 100 lb. Revised Standard B.H. The 45 ft. rail is laid on 18 sleepers, 9 ft. by 10 in. by 5 in., except at joints where the width is 12 in.

On the L.M.S. a trial has been made since 1936, of 110 lb. F.B. rails in 60 ft. lengths on 24 or 29 sleepers. The trial lengths extend altogether over five miles, and in 1939 six more miles were laid, with a further five miles of 131 lb. F.B. rails. It was desired to obtain proper comparison under similar conditions.

On the Continent of Europe, the International Wagons Lits stock has a width of 9 ft. 8 in. and a height of 13 ft $1\frac{3}{8}$ in. but, actually, stock with a width of 10 ft. 4 in., and a height of 14 ft. $\frac{1}{2}$in., can run in most parts. On German railways 49 kg. F. B. rails are used, 30 metres long, on 46 wooden or steel sleepers. In France perhaps the highest standard is on the P.L.M. section where a 62 kg. F.B. rail, 24 metres long, is carried on 40 sleepers, but 44 sleepers have been used for this length, and 27 metre rails are in use. The Belgian National railways weld together two 27 metre lengths on electrified tracks, and insert 98 sleepers.

In North America, the heaviest track is used. A centre to centre width of 13 ft. between tracks and a height of 15 ft. 6 in. allow much larger and heavier locomotives and stock. The standard length of rails, all F.B., is 39 ft., but they have

been welded into 780 ft. lengths and, after laying, again welded into a continuous length of about a mile. There has been a great advance in rail weight since 1893, when the Amer Soc. of Civil Engineers designed 60 lb. to 100 lb. rails. The American Railroad Association, now the Assocn. of American Railroads, redesigned these rails in 1908. In 1922 the A.R.E.A designed 130 lb., modified later to 131 lb. The heaviest rail in use by the Pennsylvania weighs 152 lb. Owing to the heavy axle loads, up to 34 tons, sleepers are 7 in. deep. As many as 3,539 sleepers have been got in per mile. Ballast may consist of a soling of 10 in. to 14 in., and a total depth of 24 in., it being considered that if any money is available it is best spent on ballast. One railway widens formation from 18 to 22 ft. in consequence? of the deep ballast.

17.—Broad Gauges.

Since the 7-ft. gauge of the Great Western of England was converted to standard gauge in 1892, the 5 ft. 6 in. gauge (1·676 metres) is the widest in use. The first railway on this gauge was opened in India (1853), and it was used for the trunk railways in Ceylon (1865). Elsewhere it is the gauge of Spain (1875), and Portugal, for the principal railways of the Argentine Republic (1862), and in Chili (1852).

In India the heaviest rail used is 115 F.B., but a 90 lb. rail is extensively used. On the G.I.P. Railway there are many miles of 100 lb. B.H., and on the East Indian 100 lb. D.H. in Denham and Olpherts sleepers. The standard length is 36 ft., but 42 ft. rails also are used. As many as 15 sleepers to the 36 ft. rail length are inserted. Nearly half the sleepers in India are of steel or cast iron. The loading gauge is 10 ft. 8 in. by 13 ft. 7 in. The Khyber Railway (1925) and the Bombay Harbour Branch were built to a new loading gauge 12 ft. wide by 15 ft. 6 in. high, but the universal adoption of this must await gradual rebuilding.

After India, the Argentine Republic has the longest length

of 5 ft. 6 in. gauge railways, British owned. The standard weights of rail are 85 R and 100 R, flat bottom, in lengths of 40 ft , now being welded by the flash-butt process into lengths of 120 ft. These are laid on 17 Quebracho hard wood sleepers to the 40 ft. length, the dimensions being 2·74 m. by 0·24 m. by 0·12 m , but on electrical sections the dimensions are raised to 3 m. by 0·25 m. by 0·12 m. Rails are generally spiked direct to the sleepers, but cast steel chairs with clips and bolts are used also, or be fastened by coachscrews. Stone ballast is used on sections carrying heavy traffic near the cities, but in many sections shell ballast, and even earth, has to be used.

The 5 ft. 3 in. gauge is the standard for Ireland, Victoria (1854) and South Australia, and for, amongst others, the San Paulo Railway of Brazil, where the track consists of 90 lb. B.H. or 100 F.B. on 2,415 sleepers a mile. It used to be the gauge in the Canterbury Province of New Zealand. The Victorian Railway has rails up to 110 lb. in weight and welds them into lengths of 225 feet.

The gauge used in Russia, including the Trans-Siberian Railway, is 5 ft. (1·524 metres). It is used also in Estonia, Latvia and Finland. The rail weight in Russia is 86·7 lb., but 121 lb. rails are contemplated, on 2,960 soft wood sleepers to the mile.

18.—Three Feet Six Inch Gauge.

This gauge (1·067 metre) may be termed the British Tropical Africa gauge, but it was first adopted in the Union of South Africa in 1860, and extended when the standard gauge was converted in 1872-81. It is the gauge of the Gold Coast (1898), Nigeria (1901), Rhodesia (1893), Nyasaland, Belgian Congo, Portuguese, and Sudan Railways, while the metre gauge Kenya and Uganda Railways may be converted to it. The general structure gauge is 14 ft. 2 in. wide by 14 ft. high, but in South Africa only 10 ft. wide by 13 ft. high. On the Sudan Railways it is 15 ft. wide by 16 ft. high.

This gauge is used in Central, North and West Australia, in Queensland, Tasmania and New Zealand, since 1863, followed by conversion from the 5 ft 3 in. and standard gauges in 1870. It is used also in Japan, the Netherland East Indies, Manila, Newfoundland and Jersey.

The rail weight in British Tropical Africa is standardised at 80 lb. F.B., but in South Africa, 96 lb., and in Japan, 100 lb., rails are used for electrified track and heavy gradients. In West Australia 60 lb. and 80 lb. ~~rails are used.~~ There are many miles laid with steel sleepers in Tropical Africa on account of the white ant.

19.—Metre Gauge.

On the Continent of Europe this gauge is used for secondary and light railways, but in other parts of the world trunk railways have been built. In India it is possible to travel 2,061 miles, with one break at a wagon ferry. In Burma it is the gauge of the State Railways. It is standard in the Federated Malay States, in Siam and Indo-China, and it is used in part of China. In Africa the railways in Kenya (1905), Uganda and Tanganyika, part of the Algerian Railway, and small lengths elsewhere, are on this gauge. In South America it is the principal gauge in Brazil, while there are over 30,000 miles in the Argentine, extending across the Andes into Chili. The Antofagasta and Bolivia is now on this gauge, parts of it on the 2 ft. 6 in. gauge having been converted. The metre gauge preponderates in Iraq and the Hedjaz Railway has been converted to it.

A rail weight of 41½ lb. has been steadily raised to as much as 75 lb. in India and the Argentine. The loading gauge in India is 8 ft. 8 in. wide and 11ft. 4 in. high.

20.—Narrow Gauges.

Although the 2 ft. 6 in. gauge (0·75 metre) is used in most countries for short feeder lines, there are quite considerable

lengths in systems in India and Ceylon. The Egyptian Delta Railways (1897) and Sierra Leone Railway (1899) both are on this gauge. Heavier axle-loads are causing the weight of rail to be increased to 50 lb. or 60 lb. The loading gauge in India is 7 ft. 8 in. wide by 10 ft. 7 in. high.

The 2 ft. (60 cm) gauge also has been adopted over quite considerable lengths in India, and a 40 lb. rail is in use with 8 ton axle-loads. The loading gauge in India is 7 ft. 2 in. wide by 9 ft. 7 in. high.

CHAPTER II.

MAINTENANCE

21.—Rating of Track.

Wherever an analysis has been made of the number of man-hours required to perform a particular job efficiently, the cost of investigation has been fully justified by the economies effected. Better methods have been evolved, the knowledge has been passed on throughout the system, and the gangers are stimulated by the comparison. Analysis must take account of the seasonal conditions in which each operation is carried out, and an equal out-turn cannot be expected in the absence of such close supervision. No two lengths of track, allotted to a gang under the method of equating mileage by mileage alone, require the same amount of work. As the track wears, more and more help is required. If the track is unballasted an addition of two-thirds of the ordinary gang may be necessary, while the encroachment of dense jungle must be prevented.

High speed passenger trains and frequent goods trains cause much more work on a mile of main line than a few trains daily on a branch. There must be a certain minimum of labour on account of such factors as sudden storms in the tropics, when the men are called upon to patrol at once. These factors are common to both main and branch lines unless motor cars are supplied to branch line gangs, in which case only half of the normal gang plus one driver may be required.

A Committee of the A.R.E.A. in a report of 1928 took the figure 40 as cost of minimum upkeep, adding 3 for every

million gross tons, and 1 for every 5,000 passenger coaches carried yearly by the track, with 1 for every 8 m.p.h. running speed. A figure of 100 should represent track requiring the most labour. On analysis of labour actually employed on several divisions the method worked out very well. In the "Railway Engineer" for June, 1929, the author analysed certain sections of the Eastern Bengal Railway by this method which seemed reasonable.

Double track requires about 1½ times, and quadruple track requires only 2½ to 3 times the labour required for single track, by this method of calculation. On single lines passing sidings may be rated at half, and other sidings in small yards at ⅓ of the same length of main track, as rated. A change of direction due to a curve, that is curved track, is rated in the U.S.A. at one mile to every 200 degrees of central angle

Points and crossings giving access to sidings cause a considerable amount of extra work. One method of rating these, on the North Western Railway of India, is to add four times the actual turnout length on main lines, three times on branch lines, and to add twice the length in yards. The Author suggests a furlong for a facing point, a furlong and a half for a single slip, and two furlongs for a double slip. A trailing point is taken at half a furlong and so on, down to ⅛ furlong for a derail. All these distances are to be rated for the traffic likely to use them. The extra labour thus calculated works out considerably less than by the A.R.E.A. rating of one mile of main track to 12 main, or 20 other, switches, three double slip, or six single slip switches. In India, for the metre gauge, one man may be allowed to six switches, and, on the narrow gauge, to eight switches.

The correct rating need not be argued about, but it is only fair, on railways where premia are given for good upkeep, that sufficient labour shall be supplied and distributed as fairly as possible.

22.—Distribution of Labour Force.

The labour may be distributed in two ways. Small gangs may be housed at intervals all along the track. This is probably the best plan in the tropics where with the better watch on the track legal liability for accident may be avoided. It may also be difficult to obtain occupation of the line for moving large concentrated gangs, with motor transport and mechanical tools, by the second method of maintenance, which is very suitable for a branch with light traffic. In any case the track must be regularly inspected and this causes a slight addition to the strength of the gang, while on sections of very busy traffic a special watchman may have to be added for the safety of the gang.

The strength of the length gang must be fixed by the amount of work to be done, usually in the tropics a mile of thorough repair in a month. The very large yards, such as hump yards, should have separate gangs, partly because in case of derailment labour should be on the spot.

In Great Britain, on the Great Western Railway, a ganger with a sub-ganger and four men are allotted to 2½ route miles or 6 miles of track including sidings. On branches 10 men with a motor trolley maintain 15 miles. On the L.N.E.R., over one division, the equation of work is carried out on a basis of one man to 2,500 yards of main line. Systematised maintenance was adopted after the work to be done had been studied for two years, and even now there is elasticity in the system. Certain weeks are allotted to certain classes of work, but five weeks in the year are allowed for special work, or work in arrears, as ordered by the Inspector. In one week the ganger is allowed to allot the work. For four months in the winter, on Saturdays, the Inspector's instructions are carried out. On Friday afternoons, the work is carried out in station yards, throughout the year. Forty per cent. only in man-hours is allotted to routine work according

to the schedule. Emergency work, however, always has priority.

For eight weeks the ballast is cleaned and renewed and the cess is weeded and trimmed, while in another four weeks ditches and drains are cleaned out and the grass is cut and burnt. Two weeks in addition are allotted to spot-sleepering, but they may be put in by Inspector's instructions.

The track is inspected and reported on in considerable detail twice a year by the Inspector, once by the Chief Inspector and once by an Engineer. On the report form there is space for drawing attention to matters in which help may be required. One advantage of systematic maintenance is that all concerned know exactly what kind of work is in progress at a given time, and a smaller variety of tools has to be carried about.

In France about 1·3 men are allotted to each mile of double track, but where through mechanical packing by a large gang is the rule only six men maintain 16 miles.

Excluding mates and keymen in India, on the broad gauge, 2½ men a mile for single main line should suffice and two per mile on branches, or per mile of track where it is double as in crossing sidings. In large yards two miles of track may count as one, and in small yards four miles. On the metre gauge, two men a mile are allowed on single main line, and 1½ on branches. On narrow gauges, the allowance is 1½ men a mile.

The other method is to reduce the length gangs to the minimum compatible with safety and to employ large gangs, equipped with mechanical appliances, to go thoroughly over the track once a year or so. One advantage is that men do not have to change tools so much. The concentrated gangs can also do heavy renewals. In the United States a gang of 95 men has overhauled and resleepered 65 miles in six months, while another gang of 275 men has reballasted and replaced 700 sleepers a mile, with a lift up to 4 in., at the rate of 8½

miles a week. Careful programming all the year round is required, but the efficiency and equipment of the large gang of experienced men will probably enable a smaller number to be employed than the total withdrawn from the length gangs, who also should work with the large gangs in all but key positions. The gangers can point out the spots where special attention is required, and the gang men will learn to work more efficiently.

The large gangs may be preceded by a survey section, measuring deflections under load, aligning the straights by instrument and adjusting the curves by string lining. A thorough repair in this manner will leave little to be done for a year and even more, as has been shown on the Nord system of the French National Railways, where 192 men-months with mechanical packing maintained the track in good condition for two years, against 264 men-months with length gangs. These were reduced from 11 men to 6.

The strength of the length gangs can be further reduced by a high standard of track. At the time of great financial difficulty on the railways of the United States, the labour force was cut down to the foremen only.

In programming the work, there may be a variation in the number of men employed in the large gangs. The seasons must be taken into account, and the work reduced in harvest time.

When the traffic is very heavy, delays to work become very frequent, in fact sometimes jacks are operated three times and have to be dropped again because trains pass. It becomes necessary to work at night, and even then long-distance and goods trains pass, if not quite so often. Oil flares are not satisfactory, and acetylene lighting is probably more costly than electric lighting. An 8-h.p. engine and dynamo will operate eight 1,000 c.p. lamps, lighting 605 feet of track.

Motor rail cars, carrying 20 men and the tools, have been found to save more in man-hour cost than the extra cost of

running, while trailers can carry material much more efficiently than material trolleys, but they have to be maintained in a high state of efficiency. Motor rail-cars must be given "Authority to Proceed," and either they must clear the section altogether or, if taken off the track, must be plugged into a connection, which will enable telephonic notification to be given that the track has been vacated. They should be held there until released electrically by permission of the Stationmaster or signalman.

In the Argentine, on broad gauge single tracks, by the use of motor cars the force has been reduced by 30 per cent. and the surplus gangers are employed on patrolling. The cars are periodically overhauled by travelling mechanics, each having charge of about 40 cars, which draw one or two trailers for materials.

Rules for the maintenance of motor-cars should be simple but comprehensive. Particular attention should be paid to the brakes, the linings of which wear out and should be examined periodically to see that sufficient is left. Petrol and oil filters require cleaning in dusty countries. The radiator must be filled and kept in good shape, for overheating means disaster to the engine in the tropics. The battery requires distilled water. Gaps between ignition, distributor, and sparking plug points should be adjusted.

The cars must be sufficiently large to give seating accommodation for the whole gang, one or more of whom should be able to face along the track so as to give warning. No one must sit on material carried. No one must change position with another, nor get off, while the car is running. Tools should be carried in removable racks, or trays, which should be out of the way of the men's feet, but easily released if the weight of the car has to be reduced for removal from the track. The men should be told off to each operation necessary to remove the car and trailer, if any, quickly, and understand a regular drill for doing so, preferably at a runway, ballasted (not

planked) up to an inch or two below railhead. The engine must not be running while the car is being placed on, or being removed from, the track. The speed must be limited and there must be no over-running in order to get to or back from work. The driver must pass the usual examination on the Rules and for sight and hearing. Trailers must be tight coupled and no towing of trollies can be allowed.

A travelling fitter and instructor should be employed to inspect and overhaul cars at regular intervals. Records of performance should be kept, and the cars should be sent into shops just as locomotives are.

23.—Duties of a Permanent Way Inspector.

The Inspector is an important link in the chain of organisation. He is held personally responsible for the state of the road. He must make it safe and elastic, as economically as possible, and only when he is sure that he really has a good road should he allow such work as dressing the ballast to a line. He must be thoroughly acquainted with Working Rules and Standard Dimensions. If a rail has to be renewed he or a sub-inspector must be present, and if a rail is broken he must send the pieces to headquarters for inspection, being careful to wrap the broken ends to keep them from rusting and to note every mark on the rail.

He must constantly carry and use a notebook. An account has to be kept of material received from stores, laid in the line, or taken out and stacked. Scrap should be classified and kept in separate heaps. This saves sorting at the depot for sale. He must also check from time to time the stock held in his own imprest for casual renewals, and those held by the length gangs. These imprests are best fixed on the maximum and minimum system, indenting when the stock falls to the minimum to make good to the maximum allowed, and this should be kept as low as possible.

The Inspector must walk or trolley as often as he can over the whole of his section, carefully noting all defects in his note-book with mile and telegraph post sites, and instructing the gangers to make them good. He should frequently travel on the locomotive, from the footplate of which he can detect weak places better than from a light trolley, which may not deflect the road sufficiently. He is provided with an engine-pass for this purpose. As a matter of routine he should watch the behaviour of the track under passing trains. Loose or "dancing" sleepers would otherwise escape his notice, although cracks in the ballast at either side give an indication, while sometimes mud is squirted up and discloses a water-pocket. Gangmen also should watch the track as it comes under load.

He must stop at each gang to muster the men, to give orders to the ganger, and instruction to the less skilled men. He should also exchange worn out tools or those to be reconditioned. He should at intervals minutely examine all bridges and culverts, points and crossings, and observe whether the signals are working properly, especially at night, reporting poor indications to the Signal Department, and satisfying himself that the signal wires are free of obstruction by weeds. Once or twice a year he has to certify that his track is in good order in all these respects. He must at once report to the assistant engineer any defect, or developing defect, in the permanent way, bridges, etc., taking immediate steps on his own authority to restrict speed, if necessary.

All accidents must be reported to the officials concerned, and "Safety First" must be taught to the men in carrying out their duties. He may find modifications desirable to the many hints which are given later, but he should never overlook a breach of orders even if no accident results. A valuable workman is not easily replaced.

Sub-inspectors may be a link between the Inspector and the length gangs, but it is certainly undesirable if the sub-

inspector becomes merely a link in a chain of correspondence. They are probably better employed for large marshalling and other yards, where a trolley is not required.

The Inspector should always carry with him on the trolley a supply of fog-signals, two large banner red flags, handlamps, a gauge and telegram book.

When trolleying, the best plan is to look two or three rail lengths ahead, and in particular to watch for hogged joints, especially on curves at spots where the fishplates show darker than the rail. If one side of the track is low at a joint the track may look out of line, but experience will teach which is the real defect. From time to time the top table of the rails nearer to the trolley should be watched, because any deviation of the bright part of the surface indicates poor packing on one side or wrong cross-level. The bright side of the outer rail on a curve should be evenly worn, and if any bright spot shows on a fishplate the cause should be diagnosed. The Inspector can hardly be expected to stop continually and use a lining instrument, but he must train his eye to a high degree of accuracy in observation. At regular intervals he should check all curves.

24. Duties of a Ganger.

The ganger, whether he is called foreman or mate or by some other local name, is in charge of a length gang, which should be kept together and work under his orders and supervision on all the ordinary jobs of maintenance. ~~On the~~ approach of a train the gang should move in a routine manner so that there may be no collision or hurting other members with carelessly carried tools. He should never put off repairs and, therefore, the selection of tools to be carried must include a few of all sorts. He is also expected to walk along his length (which may take one-third of his time) and note defects, but he cannot leave his gang for long if they are unskilled. He should certainly be there while they are working on curves,

points and crossings, and test the superelevation regularly. In addition he has much to attend to, to repair fencing and clean out water-channels, points have to be greased, signals and signal wires on his length must be kept clear of growth, and grass cut and burnt. In time of danger from flood and at certain other times he must be prepared to turn out the gang for patrolling. Accidents may cause an interruption of work, and unloading of heavy material for the operating department may be required, so he should try to keep some time in hand. The Inspector may call on his gang for work elsewhere.

He is also responsible for tools and materials, which will include a small imprest of track components, and of these he must keep some account. Old, small material (not only that used for Permanent Way) should be salvaged daily, and classified in separate stacks or bins, and his capacity to do this well is one qualification. Salvage will reduce the chance of mischief. He should keep some record of the number of man-hours spent on the different jobs, and report to the Inspector on his rounds. He should pay particular attention to new hands, and so should their fellow gangmen, for safety's sake.

When the allotted length is twenty miles or so on a branch line, he can be supplied with a motor tricycle, light enough for him to remove from the track unaided. A warning, however, is necessary. At the end of an inspection it is natural to desire to return at speed, but it is the habit of boys to place stones on a rail, or worse to hammer a spike into a wide expansion interval, and fatal results have followed a derailment.

The efficiency of gangers may be stimulated by annual premiums, awarded on a system of marking, somewhat as follows :

Top.—Longitudinal level 10 ; cross level 10 ; rail seating 5.
Line.—Alignment 14 ; gauge 8 marks.

25.—Duties of a Wrenchman or Keyman.

The keyman on railways in the tropics relieves the mate of track walking and is usually given the supervision of the gang during the mate's absence, receiving a slightly higher pay, although it is a question whether his duties make him competent for this responsibility. His principal duty, however, is the daily inspection of the track, walking down one side and returning on the other, driving loose keys, adjusting anchors, tightening loose bolts (see Art. 28), and replacing broken fastenings (working through his length methodically), besides reporting defects beyond his capacity to remedy to the ganger. He must pay attention to line and gauge when redriving loose keys on steel sleepers. He should not be encouraged to rush through this work and return to the gang. The tapping of lifted spikes is to be deprecated, as they will gradually lose all grip. His tools will be those necessary for the type of track in his charge, and he must carry a small supply of small material, because theft, mischief or even sabotage may be expected, detonators and banner flags to block the line.

A warning regarding the issue of too long spanners is given elsewhere.

In the Federated Malay States, proper patrolling is checked by the interchange of boards at the ends of the lengths. It is a question whether inspection should not be organised differently. In France the inspection is carried out by men unattached to any gang, quartered at stations, with definite lengths to inspect. It may be taken that a man can walk twelve miles a day, but much longer distances can be covered by a pedal bicycle trolley, at the risk of overlooking some detail. If the inspection is carried out in pairs, one man can go for assistance while the other remains to protect the track and place detonators at least a quarter of a mile away, because trains cannot be stopped in a shorter distance. In order to

keep down the weight of the bicycle, tools and material should be carried on the person.

The provision of a heavy type of track makes constant inspection less necessary, except at known points of danger, and an inspection once a month is considered adequate on some railways. In the United States, a track inspector may have a length of 60 miles of single and 35 miles of double track to patrol. He inspects all switches daily, bridges at frequent intervals, fills switch lamps, paints derails, delivers small material and supplies, and instructs the less experienced gangers.

In large yards track walking is essential, there are many turnouts requiring special inspection, gauging, and daily oiling of switches, so that the patrolling force should be increased

26.—Hand and Machine Tools.

The equipment of a length gang must depend on the class and standard of permanent way (and there may be many old types in sidings), and on whether the line is fenced or hedged, while a certain amount of grass-cutting may be required. The weights to be carried about should receive consideration. A gang of 10 men may require 194 tools of 42 different sorts.

The following is a comprehensive list :

Permanent Way.—Adzes, augers, pick-axes, baskets, beaters, wooden or steel, punners for pots, chisels, clawbars, lifting bars or hand-jacks, sets of flags, banner flags, cases for hand signals and time-sheets, detonators, rail gauges, ballast forks, clearance gauges, keying hammers, 12 lb. sledge hammers, 7 lb. spiking hammers, hand hammers, "jim-crows," spirit levels, hand signal lamps, pharwas or mattocks, ballast rakes, chain slings and bamboos for carrying rails, rail ramps, sleeper tongs, ballast screens, fishbolt spanners, box spanners, shovels, straight-edge or level board, steps or inchboards, T-square, track gauges.

Fencing or Clearing Weeds, etc.—Axes, billhooks, buckets, weeders, pruning knives, sickles, watering cans, pliers.

Miscellaneous.—General Rules, tool-box, chisels, cold set, drifts, padlocks, oil-can, punches, ratchet brace and bits, Clyburn spanners, goggles.

Tools should be placed in racks or sheds after work, inspected very frequently, perhaps daily, and kept in first class order. Track gauges are sure to become worn, and should be tested periodically by the Inspector. Handles if worn reduce the output of work and may cause accidents. Care should be taken that someone else does not use one discarded. Fishbolt spanners slip after wear, slewing bars become blunt and cannot readily get a hold in the ballast or soil below the ballast, sledge hammer heads become mushroomed, augers soon become worn and give trouble, especially if they are dropped about, for they are delicate tools, and adzes, if not very sharp, are positively dangerous. The ratchets of lifting jacks get worn. A system of exchange for reconditioning can be worked out, or the Inspector's blacksmith sent out to sharpen the tools at intervals. The time lost by working with inefficient tools is seldom appreciated, but it has its share in increasing expenses.

Tools should not be misused. Shovels are used for leverage, such as for lifting sleepers when packing. Spikes are hammered in with beaters, which are of a different steel to that of spiking hammers. Handles of spanners are forced between fishplates and the rail web to remove the plates for oiling.

Some tools require small additions for their safer use. Chisel heads can be protected by a piece of brake hose about 2 in. long, projecting ¼ in. above the head. A brittle spiking hammer should not be used instead of a sledge. A sheath on the beater handle may save wear or breakage by hitting the arris of the sleeper. Crowbars should have marks on them where they should not be held or damage to knuckles may result if spikes draw suddenly.

On electrified thirdrail track rubber sleeves may be fitted

over shovel and beater handles. Shovels may have a smaller width, and the beaters be deprived of the pick ends, so that swinging tools may not cause a short circuit. Steel bars and steel measuring tapes may do the same. Rubber mats may be provided.

Many tools are driven by machines, either in batteries or singly. In countries where wages are high, it may be possible to justify their use by comparison with the wage bill alone A machine hour, however, costs not only the cost of running but also interest, repairs and depreciation, spread over hours worked during the year, and hours should be kept as high as possible by careful programming. Overhead charges of 20 per cent. for one shift become only 30 per cent. with two shifts. With a 48 hour week it will be a fair maximum to get 2,500 hours per machine per annum. Hand tools, however, also involve "overhead" costs. The British Great Western Railway is unable to justify the use of machines for length gangs. Generally speaking it is better to use machines with special gangs working through, if the track can be better repaired so as to stand longer without attention, or if, for instance, a very high lift is to be given in regrading.

Technical details may require modification. Machine packing is so powerful that there is a tendency to lift the track higher than is anticipated, and Structural Dimensions may be infringed. The ballast is so closely packed that there may be a shortage. Fishbolts may be screwed up too tightly, if there is no overload release. One part of the organisation may have to stand idle, because the time taken is relatively too short for the other parts to keep in step.

A machine which can be adapted to several uses is more likely to be profitable. Thus a fishbolt tightener can be adapted to drilling holes and to screwing up coach-screws. A railsaw is likely to be much more useful in a depot.

Machines are noisy, and special care must be taken for protection from approaching trains.

27.—Maintenance of Rails.

On the straight, a rail will last for many years, unless the traffic is very heavy indeed see Art. 37 On curves, the wear is very different as described in Art. 15.

A rail which shows excessive side wear can be turned end for end, or better, can be exchanged with one on the opposite side of the track, so as to present a fresh side to the traffic, but if it shows excessive top wear it is best left alone. It will not improve matters to replace it with a new rail which has not been worn down at all. Rails held in imprest should be regularly exchanged with rails in the track so that they may become worn down nearly as much, otherwise the new rail will become badly battered at the ends, when it has to be laid for a replacement.

The fact that the wear of outer and inner rails on curves is so different may make it advisable to transpose the inner and outer rails throughout the curve. Both should finally be relegated to secondary track. Every possible use should be made of a rail before it is finally classed as unserviceable, and even then it may pay to reroll it to a lighter section. Rails split at the ends or battered beyond treatment in the track may be cut and used as closers or check rails, or to replace short rails on straights at each end of curves.

Defects in rails are most likely to develop when heavy axle loads run over them at high speeds, but it must be remembered that quite moderate loads on wheels of small diameter can crush the metal by imposing high stress. Stone ballast seems to be a contributory cause. Transverse cracks on the running edge occur usually on the inner rail on curves on heavy grades and the rail should be removed. A dark spot on the running edge may develop into a wedge shaped longitudinal crack. A dark streak on the table and widening of the head may indicate a vertical split which occurs usually near a joint. A horizontal crack at the junction of the head

and the web, usually in the inner rail on curves, will be disclosed only by a mirror held at an angle, and when this just appears on the opposite side the rail is condemned. Slipping of driving wheels may cause a cup-shaped depression, which is of no importance unless it is deep. It should not be filled up by welding. Transverse fissures inside the head, caused by stresses set up by the loads, can only be shown by the Sperry Detector, and are more likely to develop in high-carbon steel. The web may be split through the bolt-holes and the rail must then be replaced at once. Nicks caused by derailments, or by mishits in spiking, and holes drilled in the base of a rail, weaken it, and a half-moon may be cut out of the base by its being seated on the shoulder of the bearing plate. A lap seam along the junction of the web and base is a rolling defect which should not have escaped detection but if one develops from inside the section, as may happen, the rail can be drilled and spliced by fish-plates.

Batter which should be distinguished from droop or hogging, occurs at the joints and is due to the pounding of wheels passing over. It is shown by loss of height in the head for a distance of 3 in. on the taking-off end of one rail to 7 in. on the receiving end of the next rail. It can be noticed in British track under dense traffic. It may be arrested by attention to the fishplates which can be reconditioned by welding or after removal formed to a camber. The battered ends may be welded up to the original section by electric arc or oxy-acetylene after a loss of not more than $\frac{1}{16}$ in., and this can be done more than once with safety, although metallurgically it can not be approved. The whole of the batter may not be due to loss of metal which may flow outwards. It is very bad in track on concrete, and on the inner rails on curves. The Fletcher fishplate which has the outer plate flush with the top of the head may prevent batter. Batter is liable to start at joints where there is no expansion interval, but continuous welding has not this effect.

On the other hand a wide expansion interval is liable to cause chipping of the rail end and flow of metal. This is avoided by grinding the two rail ends transversely to a V-shape, and this again reduces batter. The welding up of battered joints consists of chipping off defective metal, fusing on the new metal and grinding smooth. The ends may be heat treated in the field for 2 in. or 3 in., by raising the temperature to a height ascertained by pyrometer, quenching with water spray, reheating to the melting point of solder and allowing to cool, the whole operation taking about two minutes a joint, or twenty an hour.

If a rail is broken, the first thing to do is to place flags and detonators to protect the track. The strongest support and fastenings available should be applied, and trains passed over at slow speed until the rail can be changed The broken ends should then be protected from atmospheric corrosion by wrapping them in sacking, as airtight as possible, and sent to headquarters where they may be submitted to micro-copics examination. In the report all details marked on the rail should be included, see Art. 3.

Rails should not be changed during the heat of the day, especially in the tropics, but may even be cooled by water, if available. If there is any doubt, rails should be pulled back on either side on the day before, because it would be unpardonable to hold up trains while desperate measures were being tried to get the rail in. Fishbolts and nuts should be taken out, oiled and replaced previously, so that the actual change may be easily and quickly done. If the rail is too long, it may have to be cut, but if only a couple of inches too long it may be sprung into position. It is bolted to one rail, the spikes on the inner side of the rail beyond the gap are drawn and the rails barred over towards the centre of the track. The ends are then butted together, the two rails barred back into line, and spiked.

Cutting rails by sledge hammer and chisel is often done by

the slow process of nicking all round the section, but it is difficult to do this evenly and the result is usually a jagged break. With F.B. rails it is necessary only to cut the foot. The chisel is held by long tongs, and only the hammer man should look at it, but both should wear goggles. A piece of old hosepipe over the base of the chisel will stop splinters. Two good nicks are made on the top of the foot and the rail is turned over and chocked up. Then nicks are made right across the bottom of the foot and the rail is broken by a hard blow or by applying the jim-crow, when the head will show a clean break. The process takes a couple of minutes with practice. A fishplate or bolt should not be inserted between the ram of the jim-crow and the rail or it may fly when the rail breaks. A hack saw or oxycetylene flame cut may be made for $\frac{1}{2}$ in. on each side of the foot, the rail bent and hammered until it breaks.

In some cases rails develop a series of hollows, 2 in. to 8 in. apart, $\frac{1}{2}$ in. to $1\frac{1}{4}$ in. long by $\frac{1}{4}$ in to $\frac{3}{4}$ in. wide and up to $\frac{8}{1000}$ in. deep, called by some "silver spots." The spots, however, may run together in time. The exact cause is still rather mysterious. They have been attributed to rigidity of the track, or, on the other hand, to the use of brick ballast, but occur even where there is stone ballast. They may be due to small wheels of the rolling stock, which develop high stress on the rail table, but the hollows develop also on broad gauges with larger wheels, where bearing pressure exceeds 600 lb. multiplied by the diameter of the wheel in inches. They appear to have developed greatly in the United States since 1931, although previously noticed on the inner rails of curves of large and not of small radius. Slipping of driving wheels may have been the cause, for the wheels of a locomotive running at 75 m.p.h. have a peripheral speed of 100 m.p.h. The bad effect on a rail depends on the longitudinal dimension of the spot and a critical speed corresponding to that dimension. The noise is highly

objectionable, and the vibration set up causes the track to deteriorate. Rails with high elongation are recommended for such situations.

A good surface can be restored by machining or by grinding. A special car with 12 carborundum blocks used by the London Transport Board at 2 m.p.h. grinds 5,400 ft. a day, and does not entail the removal of the rails from the track. It is done at 40 m.p.h. on the Lehigh Valley. It should be done only once, and not on rails so worn that they would be unduly weakened by further reduction of the section. If rails are removed for machining, the sleeper spacing should be marked on them and they should be replaced in positions where they are supported at the same points, so as to avoid reversals of stress.

28.—Maintenance of Joints.

It has been estimated that 45 per cent. of the labour, in man-hours, employed in track maintenance is expended in work on the rail joints. An A.R.E.A. Committee, reporting in 1929 on the "Financial Aspect of Rail Joints," stated that the joint is the primary cause of rail renewal. The cost of raising joints with partly worn rails is twice that of raising them with comparatively new rail. It is necessary to keep the bolts tight to maintain the strength of the joints, and to oil the plates and bolts, so that movement in expansion and contraction may be localised and not transmitted along the track with undesirable cumulative effect. This will cause slewing of the sleepers at the joints and when the creep reaches a facing point the result may be disastrous. Joints out of square are a probable cause of "Hunting" of the locomotive with much greater lateral stresses in the track and possible derailment. It has been contended that the joints require to be squared by measuring the diagonals in each rail length.

A rail, if free to expand longitudinally, will do so at the rate

of 0·000,0065 of its length per degree Fahr of rise of temperature. A range of temperature of 100 deg. or more is quite possible, if not in a single day, certainly between extremes of temperature in winter and summer. A rail in the track (in hot weather but not in cold) may have a temperature of 30° higher than the shade temperature. The free longitudinal expansion of a 40-ft. rail with a rise of 100° in temperature is therefore, $\frac{1}{3}$ in., of a 120-ft. rail one inch, and in one mile, 41 inches. A rail in the track, however, is seldom free to expand longitudinally. Joint restraint alone may resist expansion. It is equal to the area in contact multipled by the coefficient of friction by 30,000,000 lb. per degree Fahr. The rail is held by the chairs and the keys, to some extent by spikes, especially elastic spikes, by the coach-screws, or by holding-down bolts and nuts, and even by friction on the supports. The difference in diameter between the fishing holes in the rails and the fishbolts aggregates only $\frac{1}{4}$ in.

While the theoretically possible expansion of 90-ft. rails laid at an average temperature of 60° Fahr. is $\frac{7}{8}$ in., the L.N.E.R. allow only $\frac{3}{8}$ in. for expansion. In the L.M.S. experimental F.B. track $\frac{1}{4}$ in. was allowed in a 60 ft. length with anchors. An experiment by applying 75 tons per sq. in. pressure by jacks to a length of 240 ft. of B.H. track on the London Underground Railways showed no movement at 50 ft. from the jacks or beyond that distance. On the Lehigh Valley Railroad, 138 lb. F.B. rails in 66 ft. lengths were laid practically tight at the joints at a temperature not exceeding 40° Fahr. They did not buckle up to a temperature of 100°. The track was lifted in the hottest weather without a kink developing. Anchors, however, were applied. In a mile of continuous G.E.O. track longitudinal movements were only $\frac{8}{32}$ in. contraction and $\frac{6}{32}$ in. in expansion, with a maximum lateral movement of $\frac{1}{8}$ in. between temperatures of 5° and 77° Fahr. It is held that all longitudinal expansion occurs in the 40 ft. nearest the joint of a long welded length. On the other

hand, if freedom is allowed by the fastenings, fishbolts may be shorn in cold weather if the rail has been hot when laid. This may occur also if only one joint out of many is free to allow movement.

High compression, however, may cause sudden buckling of the track, if the sleepers are not well bedded and held in place by the ballast. The spot method of renewal of sleepers appears better calculated to resist this deformation. In new track or in through renewal the sooner the ballast or even soil is thrown in round the sleepers the better. It is very desirable that the rail shall be laid at a time of mean temperature, when a further expansion of not more than $\frac{1}{4}$ in. is to be expected. The rail should be quickly secured in its place by rail anchors near the centre of the rail, even if some of them are afterwards removed, the sleepers against which the anchors abut being well bedded. The track should be gone over once or twice and intervals adjusted.

The rail may move if the nuts of fishbolts are loosened, but, if not, the nuts should be slackened on one side of the joint and the rail driven by hammering against the fishplates. A rail swung in slings may be launched against the plate by hand or may be hung from the jib of a crane. Anchors must, of course, be removed if they bear against sleepers so as to prevent driving. These rather rough methods can be improved by using a Railpuller, with a lever and ratchet, or by a stronger device with a turn screw.

Bolt tightening saves wear and tear at joints, and is better done by a special gang once or twice a year, depending on the volume of traffic. All the bolts should be tightened to the same tension, because if one bolt is too tight other bolts will be loose. Irregular tension in different joints encourages creep. Each bolt should be sounded by a light hammer on one end, the fingers being applied to the other end, in the same manner as is employed in testing for loose rivets in a girder. A chalk mark can be made on the rail, of varying length to

show how much the nut should be screwed up The joint may be raised slightly when tightening. It is immaterial that all nuts should show the same position. Tightness not neatness is required. The nut should always be unscrewed a quarter turn first, and the spanner pulled upwards so that no accident may happen if it comes off the nut. The feet should not be placed across the rail, or rupture may follow.

Tightening, however, is positively harmful if the fishplates are much worn. It draws the rail ends down and increases the trouble. It is no remedy to apply new fishplates to rails worn under the head. One remedy is to use tapered "shims" between the top of the fishplate and the top fishing-plane of the rail. Wear on the lower fishing-plane is usually slight. In some cases the plate is so much worn that metal has flowed into the expansion interval and the shim should have a notch in it to accommodate this excrescence. Shims are made of spring steel from 9 in. upwards in length and in 4 thicknesses, from $\frac{1}{16}$ to $\frac{5}{16}$ in. The depth is calculated by the void below a straight edge along the top table adding to this the void under the bottom of the plate. They should be placed by a special gang, at the same time as the annual oiling.

Another remedy is to recondition the plates by heating and drop stamping, making them $\frac{1}{16}$ in. deeper than specification, and to give them a camber upwards of about $\frac{1}{32}$ in. at the top and $\frac{1}{16}$ in. at the bottom. They should not be used with new rails in the hope that low joints will be avoided. Nor does packing higher than necessary always cure hogged joints, while extra packing of the receiving joint sleeper causes hammering of the rail end on that side. Hogged joints may be improved by light packing of intermediate sleepers up to the quarter rail length.

It should be routine practice to oil fishplates and bolts periodically, especially the fishing planes. A mixture recommended is 1 lb. of graphite to 15 gallons of reclaimed engine oil, but any heavy oil with an asphalt base is suitable.

Advantage may be taken to adjust the expansion intervals and square up rail joints. After oiling, the two centres and then the other bolts must be tightened to full pressure, and any loosening should be made visible, by a tell tale mark, so that only loose bolts will receive the attentions of the wrenchman and he will not overstrain others. A screwing machine can deal with *100 joints (four bolts) an hour*. A ratchet spanner should save time. Provision to replace damaged bolts must be made.

The space between the fishplates and the web may be filled with cinders or dust, and this must be removed. Cinders and brine drip combined cause galvanic action. If the space is clean, oiling can be done by a grease gun or a spray from a tank on a trolley. An anti-rust plaster composition of wood-flour and oil can be packed without removal of the plates.

The advice to unscrew the nuts a quarter turn on every occasion before tightening should avoid rusting of the threads and render the removal of the plates easy. In some cases it may be necessary to knock off the nuts and the ends of the bolts with a sledge hammer. A spiking hammer must not be used. The bolts may be cut by an oxy-acetylene flame in obstinate cases.

When replacing the plates, the two centre bolts should be tightened first. Then the inner plate should be driven in at the bottom, and the other bolts tightened. Next, the inner plate should again be driven in and then the outside plate, before final tightening of all the bolts. The same routine is applicable if the bolts are tightened by power. After four or five days the bolts should be tightened again, and once more after about three weeks. The length of spanner is always calculated so that excessive stress shall not be induced and no extension of the length, by a piece of pipe, for example, can be allowed. The final stress allowed is given by one hand at the end of the spanner handle. Special care must be used in replacing insulated joints.

Fishplates usually fail at the top, a crack developing over the hole nearest the taking-off end of the rail. They break under the joint itself. Combination fishplates, to join rails of differing section, tend to straighten under the load and to lift the lighter rail. Sleepers at these joints must be kept thoroughly well packed.

29.—Packing.

Packing is the principal work of a length gang, but it does not consist solely of tamping the ballast to make a firm bed for the sleepers. The top of the rails has to be restored to the proper grade, cross-level and line, including the curves and the superelevation on them. Simultaneously, therefore, the low spots must be lifted, and advantage may be taken of the opening out to renew "spot" sleepers, kinks must be straightened out, and the ballast may be screened. Regauging and the reconditioning of sleepers at the holes for the fastenings, and the driving of the fastenings a little further into the sleepers may be undertaken separately or at the same time.

A wooden sleeper road should be opened out after the winter or the rainy season so that the sleepers may be air-conditioned to some extent. The track should not be opened out for long lengths in the hottest weather, because it may buckle or move the sleepers slightly off their beds. High lifts involve a chance of buckling unless the ballast is thrown in again quickly. Disturbance of the track should be reduced to a minimum and is destructive to wooden sleepers. If the sleeper spacing at joints is close it is useless to open the track there. It is better to lift and roughly pack early in the day, finishing and lining later. The ballast must be thrown in before leaving work, because it may not be possible to get back to the same spot the next morning. The ballast section also should be restored, especially the shoulders on which the lateral stability of the track depends. Too much time need not be spent on the ballast line along the formation, but

neatness has a good effect on the men in encouragement to good work. Any shortness of ballast can be met by keeping the centre of the ballast section hollow, and this will avoid centre-binding of the sleepers.

The top on the road while it is under no load gives no true indication of cavities between the under sides of the sleepers and the ballast. The only possible way of ascertaining if these exist is to observe the depression under loading, by eye, or better still by self-recording devices.

Such an instrument is the "Dansometer" or "Voidmeter" devised by M. Lemaire on the Nord system of the French National Railways. As a train passes over, the sleeper is depressed, a spring forces a rod to follow the movement and a split ring moves higher up the rod, so that the distance of the ring from the upper side of the socket measures the depression of the sleeper under load.

It is obviously not practicable to place these instruments on every sleeper, but an estimate is made of the sleeper with the greatest void in a batch by sounding with a rod, weighing 15 lb., dropped from a height of a foot on the ends of the sleepers, and a hollow sound shows if there is deficiency in the packing. All such sleepers are marked but the instruments are applied only to the middle one of five or to two out of a larger number in a batch. On curves all the voidmeters should be applied on the inner side. The voids under the remaining sleepers are only estimated and the calculation run out to zero. It takes a short time only to place the instruments and other work can be done until a train has passed over.

Another automatic instrument, not available to the length ganger is the Hallade Track Recorder, which can be installed in any coach or compartment of a train, and record the reactions of the track under load on a roll of paper. The operator can record when mile posts or other points, as desired, are passed. A special coach can be fitted up with more delicate instruments.

A simple device, which can be made automatic, is the Track Superelevation Recorder (Tyer and Co)., on a small hand trolley, drawn by two men, on which is a swinging pointer moving over a scale, which indicates the differences in cross-level on the straights also. A magnifying mirror, set low down, in another device enables the inspection of the web and underside of the rail head.

At rail joints, on bridge approaches, and level crossings, mechanical packing is advised, so that such places may not require frequent work. On gravel ballast a small allowance may be made for sinkage, more on cinders and more again on earth. Dancing sleepers, indicated by cracks in the ballast along the sleepers, must receive immediate attention, and, if mud is present, drainage also requires attention. Every train must be causing excessive stress in the rail, which will have a shorter life.

After ascertaining the unstable spots in the track, the top must be graded. This can be done by a small spirit-level instrument between the high spots, but the usual method is to employ a height-board or target, and sighting-boards. The height-board is long enough to stretch across the track, and may be fitted with feet to steady it. It is about 8 in. deep with a white line painted on it about 6 in. from the bottom. The sighting boards are of the same height as the white line and about 6 in. wide. It is, of course, necessary to stoop or lie down, unless both height and sighting boards are raised on supports to a higher, but always the same, level. The height board is carefully cross-levelled by lifting the low rail at a high spot not further than 120 ft. from the observer, who aligns the top of his sight board, also placed at a high spot, on the white line, and directs a man to move the other sighting board along the rail, usually at joints and middles. The observer can thus determine the hollows in the rail top. If lifting the outer rail on a curve, the height board is brought to the level by using the stepped cant board on the

lower rail. It is not advisable to observe from a distance, because the curvature makes it difficult to determine the exact relation between the boards. It is, on the whole, better to work along the lower rail and to give the required super-elevation to the outer rail, especially if there are approach curves.

It is theoretically better to lift the end of the sleeper, so as to make sure that there is no slack between the rail and its seat on chair, bearing plate, or sleeper. This lift can be made by a long wooden lever, or a crowbar (not a lining bar), and a wooden block as a fulcrum. The gangmen must not sit on the lever. The road is first stripped of sufficient ballast to avoid the chance of drawing the fastenings. Only one man using a mattock or ballast fork to clear out the ballast should be allowed in one sleeper space at one time.

If, however, the tightness of the fastenings is assured, much less labour and trouble is involved by using a track jack on a wooden block which is seated on the ballast bed. It is well to take some trouble over the seating, or the jack may slip off, and, if the lift is not vertical, the line will be thrown out. The jacks may be applied at the joints and centres, or, if the rail is light, at the joints and thirds. If reconditioned fishplates have been applied jacks should be applied at quarters and not at the joints. The operator should be given an indication of the amount of the lift, and place the jack outside the rail except when grading the inner rail of a curve, where the outside position would interfere with the sighting, or along high platforms where the lever could not be worked. In these cases the track should be protected by danger flags. The ram of the jack is worked by a ratchet and should have a quick release, so that the jack does not carry the train load, if one should come along, but the bar should be removed after the lift and not left sticking up with a chance of falling over and causing an accident. The operator should take care that a sudden release does not hurt anyone. Wooden wedge

blocks may be used to release the jacks as soon as possible. It is often advisable to apply the jacks in pairs to the two rails, one operator watching the signs of the ganger and the other operator watching the levelling board. One or two men may accompany the jack operators to give a rough packing to the lifted sleepers.

The road is not yet in proper condition, because the sleepers on either side of the one lifted must have cavities under them. Whether the joints have to be lifted or not, the joint sleepers and those on either side of them should be well packed, except where the measured packing system is in use. They should have first attention when ballast is renewed.

It is not advisable, when lifting a low joint, to raise it above the proper level, in the expectation that it may settle. It will settle more under the traffic if it is high, and meanwhile a high joint will give bad running until it does settle. The remedy for a joint which settles after lifting is to give it another lift and better packing, or to search for conditions which cause persistent settlement.

Beater packing is always followed by some settlement, and therefore a general lift of half an inch or so is desirable if the gang is put on to through packing. It frequently leads to slight shortage of ballast, but lining becomes easier. Higher lifts are usually reckoned to involve an amount of work proportional to the amount of the lift, a lift of 2 in. causing double the work of a lift of 1 in. The maximum generally allowed at one time is 3 in., subject to the capacity of the track jacks, a second lift following after thorough packing, and settlement under traffic. On curves the lift should not exceed ½ in. at a time, owing to risk of derailment, and the possibility of end binding of the sleepers on the inner side must be realised if the outer rail has to be raised. With mechanical track lifters and packing, a lift of 10 in. has been made, and the line opened for fast traffic in a very short space of time. The settlement of the ballast is reckoned to be only a quarter of that following

beater packing. Usually the first lifts are better packed by hand.

The lift should be made from a lower to a higher level on single line, and in the direction of running on a double line. A shorter run-off can be allowed than on the run-up, which may be at the rate of ½ in. in a rail length or conform to practice on transition curves, or at the rate of 1 in. in the number of feet equal to train speed in m.p.h.

Simultaneously with the lifting of low spots along one rail, the board and spirit level must be in constant use to bring the other rail into cross-level. On curves a stepped board is placed on the lower rail and the level board placed on the required step to give the necessary cant. It is not possible to give a fine adjustment of cant between differences of ½ in on the stepped board, but it is much more important to make the cant equal all round the circular curve. The cross-level can be varied only at differences of ½ in. on the run-up of the cant on a transition curve, and these spots should be permanently marked. They will not necessarily coincide with the most convenient places for gauging the alignment of the transition (Art. 63).

Packing may be by beater, made of steel for stone and other hard ballast, or of wood for earth or sand ballast. The ballast must be removed below the bottom of the sleeper and care taken not to damage the sleeper, especially if it has been treated. The bottom becomes rounded and the sleeper is liable to rock. In beater packing two men work together, facing opposite ways, one on either side of rail. They drive the ballast under the sleeper for not more than 15 in. inside the rail and 12 in. outside, taking care not to make the sleeper centre or end bound. The beater must not be raised high like a pick, but worked with a rhythmic motion, the handle seldom being raised above the horizontal position.

No one should be allowed to pack in the adjacent sleeper spaces, and, therefore, the pairs must be spaced out three

sleepers apart. In through packing two pairs may pack four or six sleepers near and including the joint, and two pairs the intermediate sleepers, which do not require so much packing. With close sleeper spacing at the joints both sleepers should be packed as a single-sleeper. Having packed one way they turn about and finish the process. On double track more work should be put in towards an approaching train inside, and away from a train on the outside of, the rail. Adequate packing is shown by a dull, not a hollow, sound when the beater is used as a rammer on the surface of the sleeper, or an experienced man can tell by walking over the sleepers one by one near the rail.

In mechanical packing also the men work in pairs, and the outside man must be careful not to disturb the shoulder of the ballast. Mechanical packing has a tendency to induce a general lift of the road, and in the course of time the limits of Structural Dimensions may be infringed, or ballast may fall short. It is a difficult matter to lower a road. Mechanical packing is less destructive to the sleeper as the blows come on the tool and not on the sleeper, but uses up the ballast by breaking it into dust. A Collet 8-tool unit can pack three sleepers a minute in gravel ballast using 9 gallons of petrol per 1,000 sleepers. A wider blade is used for gravel.

For steel sleepers mechanical packing is unsuitable. Beater packing must be used to force the ballast into the inverted trough, unless the track is jacked up so much as to be able to receive the fine ballast used in measured shovel packing. The ballast tends to creep to the middle and should be loosened. Pot sleepers are usually packed by punning fine stuff through holes in the top, but sometimes the pots "blow," that is the packing runs out. In such a case, small ballast should be carefully beaten in round the rim, fine stuff poured in through the holes and watered and then punned. If clay has been used this should be broken up in dry weather or the pot may split. Pot sleepers should be entirely re-

packed with fresh stuff through a rail length, even after a spot renewal, and particularly attention must be paid to rectifying any tilt in the pots. This may be disclosed by uneven markings on the top table of the rail. The rails should be unkeyed and lifted off the seats which should be scraped and cleaned, before reseating and rekeying the rail Lifting under the pot rim before reballasting will remedy the tilt. Lining must be done simultaneously.

Plate sleepers also should be packed right through a rail length, if any low spot develops, or an even bearing on all sleepers cannot be assured, with the result that the road becomes full of hogged rails. Here again, there may be a tilt on the plate, and one man of the pair may have to pack more firmly than the other. Shovel packing is possible with more disturbance of ballast. A second packing after the passage of a train is desirable.

Packing the ballast with shovels instead of beaters was introduced on the L.N.W.R. in 1908, but has been much improved by methods devised on the Nord system of the French National Railways, extended over other systems, and in this form is in wide use on British Railways also since about 1935, in connection with the measurement of voids by the "dansometer," and even without it. Chippings of very hard stone are used, and although at first a proportion will be absorbed in the larger ballast, in time a measured quantity will give a calculated lift, and a solid bed under the sleeper. By experiment, the quantity required to make a given lift can be ascertained, and a container of standard measurement made. The ballast between the sleepers is raked out partially, just enough to give access under the rail seat and for a foot or 15 in. on each side. The shovel is laid flat, or may have a "goose neck," and the requisite quantity is poured on to it and worked in as evenly as possible, while the rail is raised slightly with a track jack, or the chippings may be poured on a tray and pushed in. Before very long the ganger can

gauge the necessary quantity without recourse to the container. A gang of six men can pack about 160 yds. a day, but it is advisable to go over the length again in about a week, since the low spots may have become high spots, being better packed The method takes longer than ordinary shovel packing, but lasts much longer, at least half as long again, and the running is much improved. It is not suitable until the track, laid or relaid, has thoroughly settled down. Alternate sleeper spaces may be left open and pairs of sleepers tied together. The method is not suitable for gravel ballast, or if a lift of over 1½ in. is made, when beaters must be used.

Another method of packing with small stuff is to use a sort of trowel, which can be made out of an old cross-cut saw blade, about 34 in long and 4 in. wide, fitted with a trowel handle. Only the ends of the sleeper need be opened to the bottom, the lift is made, and the chippings inserted on the blade and spread. This tool enables packing to be done well inside the rail. The chippings must be dry or they will bind on the blade.

30.—Lining and Regauging.

Lining is necessary to bring the track into true straights and curves, as well as possible, and for very high speeds is most important. The parallelism of the rails should be checked by measuring diagonals between four points, because bogie wheels run much better on parallel rails. A track out of line is sure to throw out the surface and cross level and even the gauge. Side wear of the rails is encouraged. Where monuments do not exist it is best to take the true centres and levels from the bridges and culverts. Lining is usually done by eye, but on curves the method of string lining has been worked out, and is dealt with in Art. 31.

There is a light track lining transit theodolite, but, if one of these cannot be supplied to the ordinary ganger, he can be given a set of ranging boards.

It should be routine practice always to line one rail, and gauge irregularities will be disclosed on the other. On curves the outer rail will be lined.

Lining is done with straight bars, pointed at one end, or both, so that they can be driven into and through the ballast, to obtain a fulcrum. It is easier to slew the track if a slight lift is applied at the same time, and the angle at which the bars should be driven is about the same as that of the slopes of the banks, about 30°, or one in two. The number of men must depend on the weight of track to be slewed, but a special track liner reduces the number. The track must be lifted first, because it is impossible to line if there are low spots in the rail, and possibly a shift may necessitate further packing

Safety First demands some care in handling lining bars by a gangman. When driving it into ballast he should look to the feet or position of the other men. When lining he should not straddle the bar, which may cause rupture, nor should two men heave with it. Bars should never be left lying about, but driven vertically into the formation to a sufficient depth to ensure that they will not fall over. They should not be used to turn rails over by invertion in the fishbolt holes. A rail fork is the right tool. Bars should be inspected for cracks, especially after they have been used to turn the jim-crow.

The ganger should stand at some distance from the work, with the sun at his back, for first lining, moving up closer and closer for final sighting with a reduced number of men. Sighting becomes difficult if the bright surface of the rail is broken by uneven wear, or if shadows lie across the rail. It is easier on a cloudy day, or early in the morning in the tropics. The eyes should be rested from time to time. On curves he should stand closer according to the degree. As the men move along, they must keep their bars away from the rail or sighting will be inaccurate. They should move forward as much as the length they occupy in lining, or by whistle and signal from the

ganger, and make short heaves so that the rail is moved over gradually. One rail only is slewed, and the other will be correct if the gauge is correct, but the ganger should look to this when the one rail is truly lined, although regauging may be deferred.

When slewing steel sleepers of the dished type, it will be necessary for one or more men to loosen the ballast under the ends with the pick end of the beater before slewing and to pack one end lightly after slewing, so that the sleeper retains a grip on the ballast. With plate sleepers the ballast must be loosened on the sides of the fins towards the direction of slewing and packed on the other side after slewing. The slewing of pot sleepers must be done as part of the general overhaul.

After lining, the cleaned ballast is thrown in and tidied up. The toe line of the slope should be dressed because this has a good psychological effect on the gangmen, and on passengers, but it is possible to spend too much time over the dressing.

Regauging is an operation which should be done right through a length, at a time when the track is not opened out, and it may require a certain amount of reconditioning of wooden sleepers. It is more important where the gauge is tight, owing to compression of the sleeper seats.

Irregular gauge is worse than uniformly tight or wide gauge. It causes lurching of the vehicles, and increased lateral stresses in the track. Wide gauge may be due to side wear on the rail head, always on curves, to canting of the rail or bearing plate outwards, or to movement outwards of the bearing plate or rail base, which may cut the spike heads. Independent fastenings of the plate to the sleeper, or gauge ties on curves, will avoid the operation of the last two causes. Tight gauge is due to the foot of the rail cutting into the sleeper, or because the bearing plate cuts in on account of insufficient bearing surface inside the rail, or because the rail foot has cut into the throat of the dogspikes holding it to gauge, by wave

motion in the rail. If sleepers get slewed the gauge is tightened and the same amount of slew at one end will have a greater effect on narrow gauges.

In regauging on wooden sleepers, where spikes or coach-screws are used, it will be necessary to draw the spikes with a crowbar, or preferably with a vertical puller, or to unscrew the screw spikes, to bore new holes, and to drive the spikes into them. If readzing of the seats is necessary, broken spikes must be driven right in with a punch. If the crowbar will not engage the head of a dogspike force must not be used to launch or hammer the bar against the spike head, but an adze should be used. When drawing spikes on the inside of a rail, the hand should not be placed on the crowbar at a point where the bar would hit the other rail, and bruise the knuckles, if the spike should draw out suddenly. The danger area may be marked on the bar. The gangman should not sit on, or pull towards himself, but bear down from the side of, the crowbar, which will require more pressure to start the spike and less as it is being drawn. Where F.B. rails are seated direct on the sleeper, there is some choice of positions for the spikes, and the sleeper can be moved transversely by adzing a new seat, provided that risk of splitting of the sleeper is avoided, and the relative positions of the spikes counteract any tendency of the sleeper to slew. The gauging must be $\frac{1}{4}$ in. slack, and the first train will seat the rail properly.

Where bearing plates are used, new positions for the spikes may be available, unless more than two spikes are used, on curves, for example. If the plates are attached to the sleeper by separate spikes, the bearing plate must be shifted. This will require chiselling of the seat if stepped or corrugated plates are used. It is best to plug all old holes, with hollow softwood trenails or a composition, and the spikes can then be redriven in the old holes.

Creswell's Compound may be used, at the rate of a pound to ten holes. Fridera is a composition of bitumen, resin and

rubber, with a higher melting temperature, and greater holding power. Another preparation, " Phylplug " is plastic and easier to apply, being wetted and rolled and tamped into the hole where it soon sets hard Where screwspikes have lost their hold, but the gauging is satisfactory, " Metospir " V section strips of metal can be wound on a mandril of the same pitch and screwed into the holes. The mandril is then unscrewed and the screwspike replaced.

On curves the outer rail will be, or should be, string lined, and the inner rail may develop a lip. Therefore, re-gauging should be done from the outer rail, but is seldom really necessary.

The gauge depends on proper spiking, and it must be a " Safety First " rule that spiking must never be done over the rail head, but always on the same side. If the spike is not set vertically in the bored hole, there is little chance of true driving. The rail gauge must be placed across the rails as near as possible and watched by another man during the driving.

A power spike driving machine with magazine clips is likely to justify its use on heavy renewals or construction only.

31.—Curve Realignment.

The importance of maintaining curves in good alignment has been stressed in Art. 15. On the older railways transition curves were not inserted at both ends of the circular portion. Gangers may have eased over a portion of the straights, but not to a true spiral curve, and parts of the circular portion have been slewed to a radius smaller than in other parts. Structures may now make it impossible to slew the whole curve to an ideal form but, although the new curve may have compound radii, the transition from one radius to another must be made gradual. If the radii differ appreciably in two successive rail lengths excessive lateral stresses are set up. Small distortions have a worse effect on curves of large radius.

A quarter of an inch of variation increases a 30 minute curve to a 45 minute curve.

In practised hands a theodolite can be used, but requires probably the work of an engineer, whose time is limited. Another instrument, Trotter's "Curve Ranger," is entirely suitable if the tangent points of the circular portion are fixed, since, once it is set, a ganger can use it. It is, however, standard practice to use the method of measuring and adjusting the middle ordinates, or versines, of overlapping chords of equal length. The method is called String Lining. The measurements can be taken by a ganger, although the corrections will propably have to be worked out, or at least, approved, by an engineer.

The measurements should commence and end on the straights some distance beyond the curve. They must be made along the outer rail and at the bottom of the side of the head, if the rail is worn. Owing to gauge widening, intentional or otherwise, the inner rail does not follow the same curve. The curve should not be touched after the measurements until further orders. It is convenient to measure the overlapping chords over a length of two rails. The method of laying rails on curves recommended in Art. 60, ensures that the rail lengths in the outer rail are equal, but if not the chord lengths can be marked with greasy chalk. A string length of 90 ft. is perhaps the maximum, and it should not be less than 60 ft., except on curves of small radius on narrow gauges. The half-chord lengths also must be identifiable, not only because the chords commence here but also because the slews will be made at these stations, which should be numbered. Pickets must be driven opposite the stations at half gauge distance from the outer rail, not necessarily between the rails. A brad driven in the head of the picket gives greater precision for measurement of the final slew. The picket must penetrate the ballast into the formation. Uneven wear of the rails, most likely at the joints, is not likely to affect the measure-

ment of the versines appreciably, but may be allowed for in driving the brad into the picket.

The string should be as thin as possible, consistent with the strength necessary to resist uniform strong tension, and it must be marked with the chord length and the half-chord length. The unit for versine measurement should be small, $\frac{1}{10}$ in., or $\frac{1}{20}$ in. for curves of large radius. Entries are booked in units, i.e. $1\frac{3}{10}$ in. = 13 or 26 units. It is easier to adjust with small units, even if it is not so easy to slew to exact measurements. Methods of calculation are given in Art. 64. While making the measurements, notes should be taken of all structures, since these may limit the amount of slew. The direction of measurement must be recorded, and whether the curve is right or left-handed in that direction, with mileages and telegraph posts for identification of the curve.

The overlapping chords may miss the worst distortion of the curve. An automatic machine has been devised by two French engineers on the Est Railway. The versine measurement is continuous and recorded on paper. Gauge widening also is recorded, while a pendulum shows variations in cant or loosely packed sleepers.

When the adjustments have been calculated, the curve can be slewed by offsets from the pickets originally driven, or from fresh pickets. These can be replaced by permanent and properly maintained monuments. Care must be taken in the design so that they shall not move and they may well record the proper cant also. They may be set at such a distance that the track gauge can be used to find the correct position of the outer edge of the outer rail, and the level board to obtain its gradient. The position of conductor rails may be a factor in determining the positions of the monuments.

32.—Casual Sleeper Renewal.

However careful the selection of wooden sleepers may have

been, some have to come out in a year or two, while the numbers may be expected to increase steadily.

The usual cause for a sleeper breaking under the rail seat is excessive packing outside the rail, so that the sleeper has a longer span insufficiently supported. This is particularly liable to happen on a curve if the outer rail is lifted to restore the superelevation. A sleeper broken in this way shows the end protruding above the ballast, but a dark discoloration at the rail seat is suspicious. A sleeper failing under the seat can be tested by a lever applied under the end, using a beater as a fulcrum and pumping the lever up and down. Sleepers often show longitudinal cracks and even fissures between the rails, and a longer life may be obtained by treating them with creosote, which is not so effective as when under pressure but nevertheless arrests decay.

In about 20 per cent. of sleepers the fastenings lose their grip and they should be tested for holding power periodically. This can be done with a light hammer, although it is more difficult to do than with rivets or bolts, where the fingers can be held against one end.

Sleepers should be regularly inspected during every occasion of opening out and those seen to be failing should be marked, left exposed, and receive special attention. Opening out after the rainy season will air-condition them. Motives of economy and avoidance of disturbance of the bedding should defer the removal of a sleeper for as long a time as possible, subject always to consideration of safety. Even a broken sleeper need not necessarily be removed. Foresight is especially necessary if the through packing is done at long intervals. Condemnation should be more severe on curves. It is tolerably certain that the estimate of the ganger will be cut down by higher authority, and, therefore, he must present for condemnation only those which are quite obviously worn out. It may be taken that only when the proportion of condemned sleepers in the track reaches 30 per cent. will through renewals

be considered imperative, while if there are 20 per cent. they may be deferred for two years Joint sleepers may be expected to fail earlier, being lifted off their seats by rail wave, and should be exchanged for others or have priority in replacement. It is seldom possible (or desirable on main lines) to turn a sleeper over, because damage from beaters must be expected. It is important to open out well when packing to reduce this.

The best time for the casual renewal of sleepers is obviously at the times of through packing, but these may be at long intervals and supply cannot always be arranged to coincide, otherwise the sleepers on arrival must be stacked and not allowed to lie about and to absorb the germs of fungoid decay. Creosoted sleepers should be put in at once or they may lose their value. It is easier to arrange supply if large gangs are employed, but they are not economical if only fifty sleepers a mile require renewal. The material train can move slowly while men on the wagons unload, by sliding not tipping, the right number per rail length according to marks chalked on a sleeper in the track. The cess should be clear of men. If two wagons are unloaded at a time the proper number is not likely to be in deficiency for want of time. Some persons have a sensitive skin and should use vaseline or oil on the hands, wear goggles and use tongs when handling creosoted sleepers. If the ballast is to be beaten up for bedding, it should be loosened with the pick end of the beater, but if shovel packing is in force it should not be disturbed, except in the centre and outside parts of the track, to remove the possibility of centre and end binding.

In F.B. track, an old wooden sleeper must be cleared of ballast on both sides and one end, the spikes drawn, the rail lifted slightly (not with an adze) so that bearing plates can be removed, and the sleeper drawn out to the side by tongs. To use a pick may spoil a sleeper serviceable in sidings. It is wicked to use a pick to pull in new wooden sleepers. Even a

maul may bruise the treated shell. A spacer has been devised which grips the rail head and levers the sleeper sideways. Steel sleepers can be drawn out or in by using tongs under the bent down ends. Only a few sleepers at a time should be inserted in casual renewal and they should be packed at once. because less stress is developed in the rail and the ganger can never tell if some emergent call may not upset his plans from packing later. It does not matter so much if the spikes have not been driven before a train passes over a single inserted sleeper.

Chairs must be put on to a B.H. rail and keyed in position, before the sleeper is slid in with sleeper tongs. Bearing plates can be placed loose on the sleeper, which is packed until the plate is in contact with the rail. The casual renewal of steel sleepers should be rare, but the rail should be lifted sufficiently, before the keys or clips are removed, to draw them out sideways into the sleeper space, and thus disturb the bedding as little as possible. The same advice applies to plate sleepers, to lift the rails until the fins are out of the ballast. They are easier to deal with if the ties between the elements are detached beforehand. Pots may be canted into place, but probably little time will be lost by taking out the rail by rail forks, fitting over the section, and replacing it. This will give an opportunity of cleaning the rail seats of all the pots thoroughly.

Condemned wooden sleepers, removed from the track, may be piled in stacks, at a distance from the line and from each other. Earth should be thrown on the top, and the ground around cleared of grass and rubbish liable to catch fire from sparks from a passing locomotive. It is not worth while to spend much labour on them unless there is a good demand for firewood. Steel sleepers continue to rust when removed and should be so stacked that water runs off them, or they lose scrap value.

83.—Cleaning Ballast.

The cleaning of ballast is not a question of good appearance only. Foul ballast causes centre binding of sleepers. The winds blow dust into the interstices, and form pockets which may turn to mud in wet weather. The soil makes a rooting ground for weeds, which hold moisture and introduce fungoid growth in wooden sleepers, it encourages white ants, and causes corrosion in metal sleepers. Dead weeds may cause fire. Drainage in the ballast is spoilt and, if weeds lie on the rail, traction effort is lessened. There is actually a bad psychological effect on the maintenance staff, who are discouraged by having to deal with the weeds continuously. In the F.M.S. an extra man per length gang has to be allowed for weeding.

Dust is a nuisance in hot dry areas. There is less dust raised if the top of the ballast is kept an inch below sleeper level but the only real remedy is to lay it with a film of heavy road oil, at some cost, from a train. The rail head does not escape spraying, and must be sanded to prevent slipping of the driving wheels.

Hand cleaning of the ballast by the length gangs is not very effective and can only be done between the sleepers. One space is cleared, the ballast in the next is loosened to well below the sleeper, and thrown with ballast forks into the empty space. The dirt and screenings left are shovelled out on to the cess and the next space is dealt with. There is a small machine to stand on the cess, into which the ballast may be thrown, screened, and returned by a shoot to the space between sleepers. For pot and plate sleepers hand cleaning is the only method.

Mechanical cleaning is better done on a large scale, but some equipment deals only with ballast outside the sleepers or between the tracks. Ballast between the sleepers must be thrown out by hand. A mole or scoop on each side of a

train transfers the ballast to conveyors and screens, returns the cleaned ballast to place and keeps the dirt in wagons or shoots it on to the slopes. To deal with ballast between and under the sleepers is difficult. On the Nord system of the French National railways, arrangement is made to raise the track itself.

On heavy grades, many cinders are dropped, up to 40 per cent. of the volume of the ballast interstices. A considerable quantity can be removed by vacuum cleaning. Dirty gravel cannot be cleaned by screening.

Ballast cleaning is not entirely effective unless the drainage of the formation receives attention. Water under the track is a great enemy, and increases the cost of maintenance. Side-drains, therefore, must periodically be cleaned out and the vegetation destroyed. The slope must be kept regular, because changes in slope cause silting after rain, and the time for attention is just before the rainy season or the season for thunderstorms. The level of the beds must be below the range of capillary action to the formation under the track. Cross drainage pipes should not be located under rail joints, be laid well down, and have a diameter of not less than 6 in. Sumps at short intervals will enable cleaning of the pipes by flexible rods. Sometimes a bulge in a bank slope indicates the presence of a water pocket. If no water is found on draining, the cause may be inability of the soil to carry the load. Piles outside the ends of the sleepers may be a cure, otherwise the formation width should be increased. Drainage along ladder tracks in large yards is very necessary.

To be efficient, weeding must be done just before the weeds, after flowering, scatter fresh seed all over the track. It is thus impossible for the length gangs to deal with the weeds quickly, and this may be required twice a year. Hand weeding may even fertilise the soil pockets. The advice of a botanist may be sought. Oiling for dust laying retards weed growth, and so does mechanical cleaning, but the only effective

remedy is chemical treatment. Burning, by a spray of oil, may be useful on the sides of the ballast and the slopes of the formation, if they are not left protected by the vegetation against side-wash in time of flood. Slopes cleared of vegetation dry out by evaporation, and stability is increased.

Chemical treatment is used in many countries. Sodium chlorate suffocates the vegetation. In a very short time the plants wilt. Sodium chlorate, however, is dangerous because there is a risk of fire. A spark from a nail in the boot, or from the locomotive, is sufficient to cause a fire, and where the chemical is used alone elaborate rules have to be drawn up for its use. In Great Britain, where all the four railways use chemical treatment, the sodium chlorate is mixed with calcium chloride, and the mixture is safe. It may be applied in powder form with sand in situations where application in solution is prohibited by electrification cables, or in solution from a tank on a trolley, or from a train. The solution must be atomised by pressure. It does not harm the protective coating of steel sleepers, but the rail should be shielded in case slipping should occur on the wet rail.

34.—Maintenance of Points and Crossings.

The weak places should be thoroughly appreciated by a study of Chapter IV. The gauge and level board must be used continually.

Approaching the turnout from the facing direction, the track should be examined for signs of creep, and the rails pulled back before it becomes excessive. The joint between ordinary track and stock rails should be well packed, and an extra amount of ballast at this point is very desirable. All through the turnout extra ballast is really necessary to give good drainage and to prevent "dancing sleepers." This applies to ladder tracks also, and drainage pipes may be laid under the ballast.

If the turnout is used much in the trailing direction, a

straight tongue, and one stock rail in advance of the switch, is bound to develop wear, which may extend for 20 ft. from the end of the turnout curve. In facing points, wear commences a little behind the toe of the tongue, where the wheels are first deflected by the action of the tongue and flange clearance is eliminated. The opposite stock rail develops wear on the top table, due to abrasion caused by slipping of wheels. The packing of the sleeper at the toe of the tongue, therefore, requires particular care. The tongue should fit accurately when closed, and sometimes flow of metal in the top table of the stock rail prevents this. The gape in the open switches should be tested on both sides.

If the toe of the tongue is damaged by chipping of the top, this may be due to one of several reasons. The tongue may not fit exactly against all the studs through the web of the stock rail, so that it is bent laterally at the toe, when side pressure comes on the tongue. This may be tested by opening and closing the points and by taking impressions of the bearing of the studs on the web of the tongue. Bolts and cotters should be tightened. The toe of the tongue may lift vertically, because slidechairs supporting it may not be level throughout. This may be ascertained by trying to insert a knife blade between the bottom of the tongue and all the slidechairs. The damage is especially likely to arise if the slidechairs nearest to the heel are too high, and packing under the heel is defective. The expansion interval may be too large and the fishplates will bend in consequence. The spacing of the sleepers, up to the heel of the tongue inclusive, should be checked. The two or three behind the planing should be spaced more closely with straight F.B. switches, because the planing of the foot of the stock rail may weaken the strength. This planing is not so necessary if the slidechairs, which must be kept oiled, are stepped to carry the tongue of a differing section.

The fastenings of the heel blocks of straight switches should

be examined and the clearances checked Any sign of rubbing on the heel of the tongue, or on the fishplates, should be traced to the cause. A large expansion interval at the joint will indicate that the tongue has been driven forward by blows from wheels trailing through the points. All bolts should be tightened up, but in order that the bolts through the fishplates and the heel of the tongue may not be over-tightened, thereby preventing the proper lateral throw of the tongue, hollow washers may be inserted so that the bolts can be tightened up fully and not by guess work.

The turnout curve should be checked, either by offsets from a straight rail, or by offsets from the chord. In either case these should be worked out and recorded in the Inspector's notebook. The gauging will be tested throughout and any signs of excessive wear of the outer lead rail, or elsewhere, will be noted. The cant, if any is given, will also be checked, and, if this is given by sloping the sleepers, particular care must be taken over the packing, or they may break. The sleepers at the crossings and at the toes of switches usually fail first, and should be replaced directly they show signs, because it is too risky to wait. New sleepers help the old ones to stand the stress, but perhaps it is better to renew all. The main line rails cut into the sleepers more than the turnout rails, and may cause fouling of gear on vehicles.

The crossing requires particular attention.

In facing turnouts the train tends to drive the V away from the points and towards the points in trailing turnouts. These movements tend to cancel out if the turnout is constantly traversed in opposite directions. Movement affects the gauge and is likely to cause a knock at the crossing. The tightness of keys, bolts and rivets, especially in facing crossings, the correct position of tapered washers, any signs of tilting of the component rails, movement of the splice rail, rubbing of the wing rails near the throat, or of the sides of the nose, and abrasion of the top of the point rail advancing towards the

nose, all should be noted. The clearances between the nose and the wingrails, and the vertical clearance between worn rails and crossing chairs or distance blocks must be checked. A measurer, with blades 150 to the inch, makes it possible to take sections where the wing rails are scored by the traffic. Motion over the turnout curve, in a facing direction, is likely to wear the splice rail and motion in a trailing direction wears the rail opposite the commencement of the curve Liners may be required on the crossing chairs or bearing plates.

The gauging of the track on both sides of the nose, and the clearances throughout the check and guard rails should be measured. The A.R.E.A. has designed a limit gauge for the purpose. The distance from the rubbing edge of the check rail to the edge of the nose must not be less than the distance from the inner side of one wheel flange to the outer side of the other wheel flange by more than ¼ in. It may be necessary to use distance blocks of smaller width to bring the worn check rail nearer to the rail to which it is attached, subject to the standard clearance, and perhaps to plane the foot of the running rail. Any widening necessary on a short turnout curve to accommodate a long driving wheel base must not affect the tolerance in guard rail gauge.

Such a comprehensive examination is not practical more than perhaps twice a year, but it will enable the Inspector to recognise the causes of undue wear and to remedy them earlier. If necessary, before taking action, the Signal and Interlocking Department will be warned to have a representative present.

The practice of depositing metal by welding on worn crossings and wing rails is common. A welded crossing is stronger than a new one, and the process may be repeated as many as four times. The cost, if done by a competent man, is about a tenth of a new crossing. Since, however,

skilled men are hard to find in some countries, and since F.B. crossings tend to develop loose bolts, it is better in such circumstances to remove worn crossings to a central depot for welding and general overhaul.

CHAPTER III

RELAYING AND LAYING

35.—General Remarks.

LOGICALLY, the operation of laying should have come first, as in previous Editions. The competition of road transport, however, has reduced the building of new railways, and many miles have been abandoned. It is possible to envisage circumstances in which the rapid laying of a new railway may be of the greatest importance, and Permanent Way men should bear this in mind. Such an operation will be better performed if the details of maintenance are first mastered. In relaying, an existing track is available for distribution of material along the track in readiness for laying from the side. When laying a new railway the material has to be brought up to the end of the section already laid, and the "telescopic" system must be used. Extreme rapidity in laying must be secondary in importance to the workmanship which will get the track into the best possible shape, and keep it up to demands made upon it. This applies also to relaying.

The amount of renewals annually required will vary. During the first few years the defective material is gradually weeded out in the course of maintenance. During a second period the renewal will be comparatively light. Then, as the term of life of one or other description of material is approached heavy extraordinary renewals will be required. Special renewals may fairly be described as such when they involve the substitution of another type of permanent way for that in previous use.

It should not be forgotten that ballast wears out. British

Railways use about two million tons yearly or about half a cubic foot per lineal foot of running track, assuming that practically none is put into sidings. These railways are not heavily ballasted compared with practice in the United States.

36.—Occupation of Track.

There is a definite advantage in obtaining occupation of the track for long periods, a week or more, in any sort of renewal, and this is the practice in Germany. This can be arranged in consultation with the Operating Department. Time will be saved in waiting for blocks to be applied or removed, in making closures between the relaid and old track, and, if power machinery is used, by continuous operation While waiting for occupation, it is possible to employ labour in other operations which do not involve breaking the track, but frequent changes in work inevitably mean less efficiency.

A train with a tracklayer may be used both for removing and for relaying, of the type of the Morris on the L.N.E R , or a pair of such trains may be used, one for picking up the old track and the other for laying the new. A cantilever girder projects over the track, and a travelling crane on the girder picks up the track complete. Owing to limits of Structural Dimensions it is necessary in Britain to saw off the ends of wooden sleepers, longer than 8 ft. 6 in , by machine, and for the same reason the Morris cannot operate with 60 ft. lengths on curves of less than 2,649 ft. radius, or with pre-curved rails or where the cant exceeds 2½ in. The lifted track is run back to a second crane, running along platform wagons for stacking, and the second crane feeds a length of new track to the cantilever crane.

If there is a double line available, by diversion of traffic to slow lines of a four-track section, the problem is made easier, gantry wagons in pairs removing the old and relaying the pre-assembled track, or working with two material trains. During a period of occupation of eight hours in the night on

the Nord system of the French National Railways, nearly 2,000 ft. were relaid, the whole of the ballast being cleaned also before the new track was laid, and packed by machine so thoroughly that within twelve hours of obtaining occupation the track was fit for 50 m.p.h.

Shorter lengths may be relaid between trains, or by cancelling goods trains, with less elaborate plant. Much can be done by light cranes with jibs, mounted on caterpillar tracks, or running on the rails and readily removable. With a crane, in Germany, four men laid 120 rails an hour against 60 with 20 men. On the Nord Section of the French Railways the new rails are laid unfished near the ends of the sleepers to a gauge of 2.30 m. With rail levers and rollers 4 men can manipulate a 47 kg. rail 24 m. long weighing a ton. The new rails are temporarily spiked and used to carry gantries which lift the old rails and enable them to be fixed to Diplorries (see Art. 39). The new rails are then drawn in to gauge on the same sleepers, which have been reconditioned.

Where continuous casual sleeper renewal is the practice, the rail only will be renewed. If the rail is of a heavier section than that in use, the sleepers will have to be readzed, much preferably by machine, travelling on temporary rails or channels. Care must be taken to take out a couple of inches of ballast from the spaces between sleepers and to clean the old rail—or bearing plate-seat thoroughly, and to drive down spikes without heads. Men must wear goggles or be careful to turn their faces away while passing. There is no need to lift the track after rail relaying. On the contrary, the sleepers should not be disturbed, or creep may result, and the gauge be thrown out.

37.—Wear of Rails and Sleepers.

On straight track and on moderate gradients, the wear on the head of a rail is small. On the broad gauge G.I.P. Railway, experience showed a loss of weight of one pound per

10,000,000 tons carried, with an average of 0 2 lb. per yard per annum. This should give a life of fifty years before the rails would be condemned for loss of weight of 10 lb. per yard on 100 lb. B H. Electrification made little difference. In the U S.A. heavier rails are expected to stand the carriage of 200,000,000 tons of traffic. Fumes in tunnels or industrial areas have a bad effect, and electrification may cause side wear. Replacement of rails in straight track, apart from any due to defects, is usually made because the rail is insufficiently strong to carry increased axle loads, but may be due to "batter" near the joints (see Art. 27). Worn ends may be cut off to obtain shorter rails. Metal, however, which has been subjected to alternate stresses in one position is not necessarily in a condition to resist different stresses over differently placed supports.

On curves the wear of the top table is supplemented by side wear, which scoops away the corner of the head to a curve, assuming more or less the profile of the wheel flange, modified by the angle at which the flange meets the rail. The slope of the worn side may become inclined at 30° to the vertical. A combination of heavy grades and sharp curvature causes heavy wear, due to slipping of the wheels and braking, and the wear may be very uneven, if the curvature is irregular.

If the gauge becomes wide, the wheels sway from side to side and the rough part of the tread wears down the top of the table more than the inner and polished part of the tread. Batter is particularly noticeable on the lower rail on curves, and is absent from the outer rail. To increase the inward tilt of the inner rail, where there is much cant, is no remedy, because the outer part of the wheel tread bears on the outer corner of the table and increases the stress.

On the Bombay Harbour Branch rails on one curve lost 7½ lb. per yard in 3½ months. There was reason to believe that new wheels wore the rails badly until the wheels themselves became worn. On the broad gauge in India generally,

wear becomes serious on 4° curves, on the metre gauge at 7°, and on the 2 ft. 6 in. gauge at 10°. On the Sudan Railways of 3 ft. 6 in. gauge 54 per cent. of the allowable loss occurred on a 4° curve in four years.

Oiling or greasing curves reduces wear appreciably, from one third to one ninth. On a 1,360 ft. radius curve on the G.I P., equal parts of point grease and graphite reduced wear to one half.

The absolute limit of wear on the head table is when the flanges of the wheels are within close proximity to the heads of the fishbolts, but before that the moment of inertia of the rail section may have been so reduced that the rail is too weak to carry the load without excessive deflection. This may have occurred by sidewear on a curve, and on the Est Railway in France, the rule for condemnation includes limits of both top table wear and side wear. The area may be reduced by about one sq. in., which is the limit elsewhere.

It is, therefore, desirable to employ means for taking a profile of the worn rail while it is still in the track. One method is to use lead strips, about 18 in. long by ⅛ by ¼ in., which can be bent by hand or lightly tapped into contact with the rail section. The strip is then divided by a chisel near the centre of the top table, and the two parts drawn apart. They are then re-assembled on a small drawing board and the outline traced. This method gives a slightly greater section than that of the rail.

On the Great Western Railway of England, taking side wear into account, on both sides if the rail has been turned, the standard 95 B.H. rail is condemned for main track when reduced in weight by 10 lb. where axle loads exceed 22½ tons, 15 lb. for a minimum of 19½ tons, and 22 lb. for lighter axle loads down to 16 tons. On the broad gauge in India and generally for all gauges one tenth of the weight is allowed, but for rails of 40 to 50 lb. only one eighth.

As the rail section diminishes by wear, the casual sleeper

renewals become more numerous. Of untreated sleepers 67 per cent fail eventually by decay, while only 40 per cent of treated sleepers fail from this cause. Some 20 per cent. fail owing to loss of grip by the fastenings. Mechanical wear is slower than physical decay.

In Great Britain the average age of treated sleepers under chairs is about 22 years with another ten years in sidings. Broad and metre gauge sal sleepers last 12 to 15 years in India. In the Federated Malay States the average life is 14 years, but some sleepers of a batch may last out for 23½ years, that is to say, one and two-thirds times the average life. A similar result has been observed in the United States, where renewals by the time the average life is reached aggregate sixty per cent. Sleepers cannot be expected to have the same life on sharp curves, where frequent regauging and transposition of rails are necessary.

The life of steel sleepers in favourable conditions may be taken at 35 years, but some have lasted for nearly fifty, and the life of cast iron sleepers at a hundred years. This does not apply to the steel cross-bars, or to steel fastenings of these sleepers. Steel sleepers are more liable to fail at the joints.

38.—Preparation of Material in Depot.

Much depends on the careful sorting and preparation of material in depot, and the Inspector at railhead must keep the depot informed of progress and of any special requirements. The exact requirement for each curve should be worked out beforehand in detail. The recommendations in Art. 60 are designed so that on curves the least amount of work shall be done in the field.

Rails should be carefully measured and sorted into pairs or stacks of the same length, with the arrows on the web all pointing the same way. Starred rails may be specially painted. A crane with one driver and three men can handle 20,000 feet a day. It will be necessary to cut some rails,

especially for points and crossings, and for this purpose a rail-sawing machine may be installed Again, it may be necessary to bend rails on a line with much sharp curvature. A drilling machine is an advantage when curves have to be check-railed, for level-crossing rails, and for points and crossing "lead" rails. A pneumatic drill will make a $\frac{7}{8}$ hole in 30 seconds, and a $\frac{5}{8}$ hole in 15 seconds.

Fishplates should be oiled, even if loosely attached to rail ends.

Fishbolts should be opened out, cleaned, and oiled before being sent out.

Wooden sleepers have to be adzed and bored (Fig. 6), and though this can be done by hand (a carpenter and assistant can do 50 a day), an adzing and boring machine will do it better. Such a machine can do 500 to 800 sleepers in 10 hours. Some, if not all, of the chairs on a chaired road will be fixed in depot; bearing-plates also, if they have separate fastenings, may be fixed. Sleepers for use on curves may have double spike holes bored on the inside. For use with hardwood sleepers, dog-spikes may be oiled or tallowed.

Steel sleepers, of the type shown in Fig. 3, should be assembled with bolts, washers and clips complete, ready to turn into position to tighten up.

39.—Material Trains.

Material and ballast train charges may be considered as labour, and the charges should be kept as low as possible by careful programming or occupation of the track in consultation with the Running Departments. Young engineers and Permanent Way Inspectors are apt to think that material and ballast trains cost nothing, although they are fully conscious of the cost of labour standing idle. Programming has reduced ballast train-days by 37 per cent.

Careful consideration must be paid to methods of unloading material. The rails can be conveniently drawn off, by wire

ropes attached to sleepers, with hooks engaging in the fishbolt holes, from rail wagons at the rear of the train. Welded rails as long as 300 feet have been dealt with in this way. Sleepers should be loaded transversely, but secured, and can thus be slid off, as the train moves slowly along, from two or three consecutive wagons, otherwise there will hardly be time to do so. A sleeper should be laid cross-wise on which the others can be slid, and will prevent bruising. The top ones in the piles require more care, and fewer men can be employed on the job while they are being unloaded. It is easy to drop out a couple of pairs of fishplates and their bolts, but other fastenings should be bundled or sacked for ready handling. The organisation of the unloading labour is worth while.

The unloading gang proceeds to distribute the material along the track, so as to save as much time as possible in relaying. It is particularly necessary to do this before relaying points and crossings.

The new material is next laid out on one side, so as to leave room for throwing out the old material on the other. Any rails which have been sagged by careless handling are straightened in a portable rail-press. All are laid out in pairs, in two straight lines, at the edge of the ballast, the ends nearly touching, with the proper clearance for expansion between them, so that the new rails occupy the exact length required right along the line. Rail ramps enable six men to handle 60 ft. 95 lb. B.H. rails across a rail or track. Six men on either side can tilt the rail into chairs. Two men only can do so with "Liffrail" jacks. It takes twenty men with tongs to lift and carry 45 ft. 95 lb. rails. Carriers have been designed with which four men can carry a chaired sleeper, otherwise an awkward load. Opposite the centre of each pair of rails are collected the proper complement of sleepers, two pairs of fishplates, and eight fishbolts. The smaller material is placed in convenient positions. Centre pegs are driven and cross-marked so as to preserve the alignment.

A form of material train is the Diplory, as used in France. This is drawn by a petrol car. Low rail gantries carry double rail lengths, already plated, and these can be traversed to be lowered into position. Low wagons carry the sleepers, there is a car for fastenings, and four ballast hoppers. The capacity is 650 feet of track. A small train of this sort can run out and back quickly from a siding at a station. The material train is unloaded at the station, but, of course, there is double handling. The Diplory train can also pick up old material, the rails having been turned in to the middle of the track over special ramps.

The old material must be picked up after relaying, except possibly old wooden sleepers, and some of these will still be serviceable. It is possible to train a gang of strong men to throw rails on to wagons by word of command. It is better to use a crane or to draw them on by wire ropes, taken round a bollard on a wagon and attached to holdfasts, but the leading ends must be lifted. Thirty-two rails in an hour can be loaded in this way. Sleepers can be drawn on by tongs until the stacks get too high on the wagon. Small material can be thrown up. It is specially necessary to pick up small material because of the risk of mischief. All used material should be run into a reconditioning depot, where it can be sorted and dealt with. Great savings have been effected in this way.

10.—Method of Renewal.

In England it is advisable on double track to relay against the direction of traffic, so that braking of trains for the necessary restriction of speed may come on the old track and not on the recently relaid track. Two-thirds of a mile can be relaid in nine hours on Sundays or by nights.

On the Shire Highlands Railway, only one or two 30 ft. rail lengths were relaid at a time, the day's work being 36 lengths with 165 men (Indian labour.)

An idea of the details of the operation of renewal by hand

labour entirely will be obtained from the description of an actual piece of work in India.

A length of F B. rails on wooden sleepers is to be taken out and replaced by F.B. rails of heavier section on steel trough sleepers with double keys and clips.

There should be telephonic communication with the stations on either side The inspector has to let a train pass before breaking the road, and must finish the job before the next train. Meanwhile some men are engaged on the road relaid previously.

Gangs are stripping the ballast from the road which is to be renewed to-day, removing all but two fishbolts at each joint, chipping sleepers to railseat level, so that the claw-bars may grip the heads of the spikes, easing the spikes. Boys are engaged in picking up the fastenings which have been taken out, oiling fishbolts, chalk marking the sleeper distances to a gauge on the new rails, etc.

After the last train has been passed (at restricted speed previously notified) over the partly dismantled road, banner flags are stretched across at both ends and detonators placed. The closers connecting the old and new rails are removed and trolleyed to the further end, the remaining fishbolts are taken out, and the outer spikes are drawn.

The old rails are then pinched out, lifted off with the rail-nippers or tongs, and deposited on the side opposite to that on which the new rails are lying. It is not advisable to leave the joints fished and to turn out a long length of rail. It may save time to do so, but it is more costly to unfish a long length on the cess.

The sleepers, which often stick on the old bed, are tipped up with light pinch-bars slipped under the spike-heads left in, or with picks. They may then be drawn by sleeper tongs and laid on the slope of the embankment, top-side uppermost, so that the remaining spikes may be drawn at leisure.

After removing the old wooden sleepers, the ballast, now

five inches low, is dressed and loosened so that the new steel sleepers can be pressed in by rolling with a light locomotive. Care must be taken to pack the ends of the renewed length to the prescribed approach slope. New graded ballast is then dropped to bring the sleepers up to the old level, if necessary, and the lift is made on the new ballast, the old ballast from between the old sleepers being thrown in after the final packing. In Germany the ballast is rolled with a motor roller before moulding transverse ridges. Another method is to form longitudinal and wider ridges, but the old ballast is hardly likely to be suitable for these. Advantage may be taken of this opening out to clean the old ballast.

The new steel sleepers are then placed, and the right hand rails. An expansion-wedge is inserted between the ends, and the rail driven close up. One of the keys at each joint must always be driven before the fishplates are fitted on, as it cannot afterwards be driven from the fishplate side The opposite rails are then levered on to the sleepers.

The wrenchmen now half-fish the joints with two bolts (or even one if there is much press for time) to hold the wedges in. They check the squareness of the joints with a set-square, and the expansion-wedges are allowed to remain in until the fishplates have been completely bolted up for a distance of eight or ten rail-lengths ahead by the following wrenchmen.

The keys are then driven, after the alignment of the sleepers has been very carefully checked. Anchors are then applied. The track is closed at the end by a pair of short rail lengths, drilled at each end, and fished with plates, the bolt holes of which have been slotted to allow a little play. This joint should be supported on a sleeper temporarily. Another device is to use an old pair of switches which allow some adjustment, but this is suitable for wooden sleepers only, to which the switches can be spiked temporarily.

A few gauge ties may save delay to the train at the last moment.

41.—Organisation of Gangs.

It is impossible in ordinary relaying operations to tell off men for one particular task throughout, as may be done in laying new track. It is necessary to divide the work into three parts. First the whole gang will be employed on preparing to break the track, when the time comes, or in improving the track previously relaid. Next, the old material must be dismantled and thrown to one side, and thirdly, the new material must be linked in.

The preliminary work has already been divided into the following tasks :—

A. Driving centre line pegs, and cross-marking them, to preserve the alignment.
B. Laying out the rails in pairs.
C. Placing sleepers in the right proportion per rail length.
D. Placing fishplates and bolts, and fastenings in the right numbers for each rail length.
E. Collecting tools in position.
F. Raking out ballast to bottom of sleeper.
G. Dealing with old material.

The work on previously relaid track is :—

H. Packing with new ballast.
I. Final straightening.
J. Fully spanning up fishbolts.
K. Throwing in ballast.
L. Collecting and stacking old material.

These gangs will not be available for the relaying work.

The gangs for breaking track will be distributed to the following tasks, in such strength as will ensure their completing their tasks in time to take up their tasks in relaying. This requires care in calculation.

A. Unfishing bolts.
B. Breaking jammed bolts.

C. Clearing over-driven spike heads with adzes or chisels.
D. Drawing spikes or screws.
E. Throwing out rails.
F. Turning over sleepers.
G. Drawing out sleepers.
H. Breaking up and dressing bed for new sleepers.
I. Spacing and aligning new sleepers, roughly.
J. Boys collecting fastenings.

The sleeper gangs will not be required if the system of continuous casual renewal of sleepers is in force, and the rails are not of heavier section, in which case mechanical adzers should be used. On the other hand, new holes may have to be bored, or spike holes re-conditioned in wooden, or washers changed on steel, sleepers.

The gangs for relaying the track include :—

A. Placing rails on sleepers.
B. Inserting expansion irons and rough straightening.
C. Half fishing and oiling joints, and lining rails.
D. Full bolting joints.
E. Marking rails for sleeper spacing.
F. Spacing and aligning sleepers correctly.
G. Applying anchors.
H. Spiking leading rails.
I. Spiking wooden sleepers and gauging opposite rails.
J. Boys distributing spikes.
K. Closer gang.
L. Packing and lining.

There will be in addition :—

Signalmen, with temporary restriction signals and banner flags.
Blacksmiths, carpenters, and helpers.
Watermen.
Gang for shifting camp, and
Watchmen.

42.—Lifting and Packing Gangs.

These will undertake the operations of straightening, lifting and packing directly the track is relaid.

The first lifting gang will level up the joints and centres of rails up to 33 ft. with quarters also up to 60 ft. The second party will pick up and cross-level the intermediate sleepers.

The packing will be by beater, as described in Art. 29.

The rails should be in line and level before the fishbolts are tightened up; the strain of bringing into exact position two adjoining rail-ends should not be thrown upon the fish-plates and fastenings.

43.—Laying New Railways.

Where a temporary railway is laid for leading cutting spoil into bank, and especially on double lines, the contractor's line is used to bring up the material and relaying methods are employed. On single lines the "telescopic" method is employed. A certain amount of material is thrown off, the material train is drawn back, the material is laid and linked, and the train is moved forward over the newly laid track so that the process can be repeated. To avoid the continual see-sawing of the train, and to economise labour, the track-laying machine has been adopted. It was found especially useful on the Trans-Australian Railway, where two miles and forty chains were laid on the best day, and two miles a day in the best week. The device is a material conveyor. A jib projects from the leading wagon (which carries most of the fastenings, vices, anvils, etc.) and conveyors run along the sides of the wagons to the ends, supported by the jib. Rails are delivered on one side and sleepers on the other, the conveyor on this side being curved out slightly. The train moves continually forward at a very slow speed.

Remarkable results have been attained by good organisation with hand labour alone, feeding from the train. On

May 28th, 1869, on the Central Pacific Railroad, 2,250 (short) tons of material were laid in 10 miles and 200 ft. The remarkable feature was that the same eight Irishmen handled 3,250 rails in this one day, or about 1,000 tons. Four men were told off to a 30-ft. rail weighing 70 lb. per yard.

Laying by hand, if the considerable numbers required are available, is probably economical compared with laying by machine, or by the use of mechanical transport, as indicated later, but the element of time saved may be the controlling factor.

The preliminary preparation of material in depot has been dealt with in Art. 38. The great question is how to marshal the train on which the material is loaded so that it may be conveyed from the train to the formation. The rails can be loaded on the wagons nearest rail-head, wire ropes, attached to holdfasts or to sleepers already laid, can have hooks, which can be hooked into the bolt-holes, and by setting back the train the rails can be drawn off the wagons on to the laid track They can then be carried by men, equipped with bamboos, slings and rail tongs, or picked up by some form of gantry, running on angle irons laid temporarily on the formation or sleepers already spread out. It will save time, if the fishplates are loosely attached to one end of each rail, because it is recognised that speed in linking depends on the time taken to fish a pair of rails together, but the fishplates must not be damaged by drawing off the rails. For heavy rails a crane may be used, but it can carry only a certain weight for a certain radius of action, so that the rails should be unloaded on to the cess. If a crane is to be used, the rails should be marked at the points for lifting, the hoist being attached to a bar, with tongs at each end. Throwing off rails from the wagons on to the cess should be avoided. It is not a pleasant business and the rails may become bent. Since there may be one or two material trollies in front of the train, the drawing off method becomes almost impossible.

If the rails come first, a practically universal practice, the sleepers must be carried to rail-head by some form of transport. The sleepers can be slid off individually, placed on carts, carried along the berm, taken off the carts, carried up the slope of the bank and spread in position. Many carts and many labourers are required. It is much better to employ a crane, travelling on caterpillar tracks along platform wagons, to lift the sleepers by slings in bundles, two or three to the rail length, on to lorries. A 1½ ton tilting lorry can carry 15 sleepers, and deliver them on the berm, or a travelling crane, working on the formation in advance of the laying, can lift the bundles off the lorries, which should have dual treads, and place them in position to be spread. This will not work well with chaired sleepers, and may be awkward where there are high banks or cuttings. Sleepers, adzed and bored, for use on curves with wide gauge must be loaded in separate bundles.

With a tracklaying machine, the marshalling may be rails and fish-plates, locomotive and tank wagon, spikes and bolts, bearing plates, tools, brake van, sleepers (these last wagons being cut off at a convenient site, and the sleepers being carried to rail head by lorry).

The locomotive should be of a light type, since it will have to work over a rough track without doing damage to it. It is not advisable to have a long train, and, therefore, a siding should be laid not too far behind rail-head, so that a second train may be brought up without delay, while the unloaded train runs back to the material depot. The composition of the train depends on the type of track and weights of material. A time-table must be worked out, and altered as the railhead advances, so as to ensure the regular and continuous supply of material.

44.—Organisation.

In view of the widely differing types of permanent way in use, it is hardly of use to give examples of numbers employed

The various operations will be mentioned, and figures of duty given. The tasks should be corrected by experience

Preliminary Work.—Soaking and running down half the bolts, should be done at the rate of 40 large or 50 small bolts per man per day, but can easily be doubled by the use of ratchet wrenches.

Adzing sleepers and restacking. A carpenter can do 50 large and 75 small sleepers a day.

Boring sleepers. This and the previous operation is much quicker done in a machine, but if the line is much curved, and the gauge requires widening, it may be necessary to do a great deal on the spot. The numbers bored per man will be about the same as in the last operation, unless bearing plates are used, with more spikes, on curves. One auger should bore 1000 holes in depot, 700 in the field

Bending rails to curve. This is only necessary for very sharp curves See Art. 59.

Sorting, measuring and marking rails. A task of two tons per man per day is reasonable, but a crane can do much more.

Loading material train. One ton per man per day.

Straightening rails at rail-head and cutting. This refers only to such rails as may have been deformed in unloading, and cutting rails as closers near facing points of stations.

Levelling formation. A fairly smooth surface is required for good work.

Placing centre line pegs and measuring.

Moving and guarding camp, etc.

Watering and coaling gangs for the material train.

Linking at Rail-head.

Unloading material. This gang will depend on the method employed, and it may be possible to utilise labour standing idle for the moment. But with a track-laying machine gangs must be told off for work on the train.

Loading on trollies and pushing. This is hard work, but not so hard as rail carrying and placing, and the gang may

interchange with the rail carriers. A great reduction is possible by employing a device of Mr A. T D. Anderson, of the Bengal Nagpur Railway. He employed levers pivoting on an ordinary material trolley axle, and provided with rail tongs at the short ends of the levers. The rails, first thrown off the train outside the track, are rolled over up short ramps into the centre of the track after the train has been set back, and are transported, four rails with the proper number of sleepers, by eight men with a pair of axles and wheels. Angle irons are used to carry the wheels beyond the length last laid, over the sleepers taken off the trolley. The labour required to lay a mile of track has been reduced from 1,024 men-days to 128 men-days Fuller particulars can be obtained from Guest, Keen, and Williams Limited, Calcutta.

Small stores trollies. These should be kept as near rail-head as possible, and one may carry a vice for running down obstinate bolts, a ratchet brace and bits, spare augers and spiking hammers, and a few wooden plugs for spike-holes spoilt in driving. A carpenter and blacksmith should be in attendance.

Spreading sleepers, including carriage. A carrier may handle 2 to 2½ tons daily, according to lead, allowing a load up to 60-lbs. a man, while a placer can do 8 to 9 tons a day, handling 100 lbs.

Adjusting to centre line and spacing.

Unloading rails from trollies. A small gang.

Rail carrying and placing. This is a heavy task, and not more than 70 lbs. per man can be expected on smooth and wide formation, or a total of two tons per man-day.

Expansion irons can be placed by boys, but the issue in accordance with the temperature must be carefully supervised.

Distributing fishplates and bolts. If done from a front trolley, a man should do 2 tons, and a boy 1 ton, but only a quarter of this task is possible from the train

Skeleton fishing, two bolts per fishplate, hand tight Allowing two men and a holder-up, the task may be 55 joints per man per day. This operation sets the progress, and other operations should conform in the time taken.

Straightening rail, and chalking sleeper spacing on it.

Distributing spikes, and bearing plates, if any. The task corresponds to the distribution of bolts.

Gauging, holding up, and skeleton spiking. The daily task is 200 spikes per man, including holder-up. Alternatively, the gauge-ties may be used, and all spiking done behind the train.

Distributing bolts, full bolting. The task is 110 bolts per man. On some railways skeleton fishing is not allowed, and this gang will merely have to tighten up four hand fished bolts.

Removing expansion irons.

Distributing spikes, squaring, and full spiking. Tasks have been given above.

Picking up small material.

Straightening track and correcting before packing.

Waterman, signalmen, guards, etc., and a reserve.

Packing and Lifting.

Filling earth for packing. 100 cubic feet per man from borrow-pit to track. Three cubic feet per foot run is ample.

Earth packing with the least possible lift.

Earth filling to sleeper level, if ballasting is to be deferred.

Maintenance.—Four men a mile must be told off regularly as the work proceeds.

Ballasting.

Raking out earth. The task is 300 cubic feet per man.

Unloading and shovelling ballast. This is much better done from hopper wagons, but otherwise 200 cubic feet per man can be expected.

Packing and lifting three times, eight yards per man per day on 5 ft. 6 in. gauge, and 12 yards on narrow gauge.

45.—Tools.

The following tools may be supplied :

Opening out	Ballast rakes, shovels, mattocks
Spreading Sleepers	Gauging rod, measuring tapes, chalk, pegs, and mauls or sleeper Spacer.
Unloading Rails	Bars and rail ramps.
Distributing Material	Baskets, tommy bars.
Trolleying Rails	Tommy bars, or rail forks.
Rail carrying and Placing	Rail slings and bamboos, tommy bars or rail forks, bars, sledge hammer.
Fishing and Spiking	Thermometer, liners, chalk, tommy bars, spanners, spacing rod, T-square, spiking hammers, crowbars, fulcrum blocks, mallets, rail gauges.
Straightening	Lining bars, jim-crow.
Keying	Keying hammers
Lifting and Packing	Sights, spirit-level, boards, levers, crowbars, fulcrum blocks, beaters.

Hammer and beater handles, bamboos, and mallets require many spares. Bars require straightening, and a reserve is required for exchange while this is done The same applies to tommy bars and spanners, which wear out quickly. Oil for lubrication and cleaning dusty bolts, etc., is in much demand.

Track jacks or a track lifter obtaining a leverage from shoes lowered on to a firm bed will save in lifting. With a 40-h.p. petrol engine and a 7½-kw. generator, working through 1,000 ft. cable, five men can drive over 2,000 spikes daily. The machine will bore sleepers also. A turntable is fitted to remove it from the track. If screw-spikes are used, a petrol-electric screwing machine is advisable. Material trollies are often too heavy. Portable telephones are used for obtaining permission to place motor trollies on the line and vice versa.

46.—Distribution of Labour.

Every man should have certain work to do, and there should be no overcrowding or confusion. Supposing that the material is brought up and laid out rapidly and continuously, the speed

of platelaying is only limited finally by the time required to link two pairs of rails together, and the number and distribution of workmen depend upon this entirely.

The operations connected with platelaying by the "telescopic" method may be divided into three :

(*a*) Conveyance of material to the working-point ,
(*b*) Linking-in ; and
(*c*) Lifting, straightening, packing and boxing.

Material Gangs. The regular and continuous supply of material is of the first importance, and on it the whole progress of the work depends.

One line of rails, on a curve the outer line of rails, should be linked and spiked first. The first party of wrench-men half-fish the rails, adjusting for expansion, while a second party completes the fishing of the rail-joints, after a straightening party has corrected the alignment.

The sleepers should be properly spaced, one rail being marked with chalk at the proper intervals, and these marks squared off on the other rail.

Templates should have on one side the spacing near the joints and on the other the spacing for intermediate sleepers. There is no need for templates longer than about 8 ft. The spacing on curves is complicated as there must be some "stagger."

Rail-joints are to be avoided on small open-top or girder bridges, or where a guard-rail is to be put in at a road crossing. They should be closed and the fishbolts jammed. Welding or heat treatment of joints and chamfering should be done early, after the track is in good line and sufficiently packed, but need not wait for final lifting and packing.

Much trouble and expense was caused on a certain railway, laid with F.B. rails without bearing plates, because the gangs did not place the off-side rails properly, on the adzed seats of the sleepers. The result was that to get the gauge, the

rails, not being tilted, were drawn in until they rested on a small un-adzed portion of the sleeper, and this crushed, causing the rails to tilt and become tight to gauge.

The final lifting, packing, and boxing must wait for the ballast, and possibly until the formation has settled. Hopper ballast wagons with a plough brake can effect an enormous saving of ballast and labour It is important to open out the earth packing first and to distribute only a small quantity of ballast, in the first run, otherwise the ballast gets spread out by the plough and mixed with earth. If possible, large ballast should be used for the first lift as a soling, but is not good for packing.

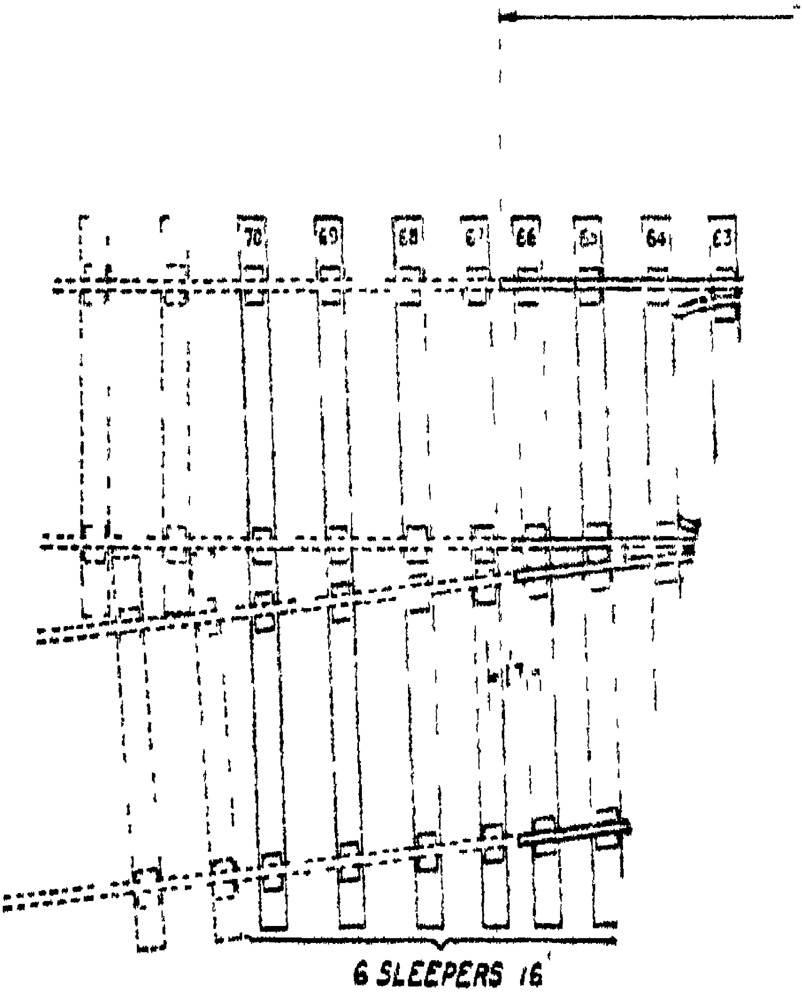
CHAPTER IV

POINTS AND CROSSINGS

47.—General Remarks.

THE object of points and crossings (Fig 7) is to pass trains from one line to or across another. The points divert the train, while crossings are used to provide gaps in the rails through which the wheel flanges can pass. Thus, when the points are set for a turn-out to the right, the left-hand wheels are prevented from continuing on the main line, the right-hand wheels have to follow the right-hand rail of the turn-out, and the flanges of the left-hand wheels have a gap provided so that they may cross the right-hand rail of the main line. It may then be necessary for both sets of wheels to cross both rails of a parallel track by "diamond" crossings, or the train may be turned into another track by a crossing and pair of points, in which case the whole of the connecting track is termed a crossover, or vehicles may be placed in a dead-end by a simple turnout. In a diamond, single or double slips may be provided to allow inter-communication between the crossing lines. Two crossovers may be got into the same length by a "scissors" crossing.

It is very necessary to standardise the nomenclature. So many American expressions have crept in through study of American works, that, otherwise, a double nomenclature is almost inevitable. In this work the following terms will be adopted and described in due course.


70
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6 SLEEPERS 16'

POINTS.	CROSSINGS.
Tongue rail, toe, heel	Wing rail.
Stock rail	Check rail
Heel block	Point rail, nose, heel
Slide chairs	Splice rail
Studs or stops	Throat
Switch (complete)	Gap
Gauge tie	Clearance
Connecting rods	Clearance block
Point rodding	Wheel flange
Lead rail	Wheel tread
Heel rail	Wheel face, outer, inner
	V crossing
	Diamond crossing
	Continuous crossing.
GENERAL	
Facing points	Double slip
Trailing points	Gathering line
Turnout	Three throw points
Crossover	Switch derail
Scissors	Triangle
Single slip	

There is nothing which impresses the public more than smooth running over points and crossings, especially at turnouts from the straight. It is not sufficient to study and obtain good running over ordinary track.

48.—Theory of the Turnout Curve.

The simplest case is that of a turnout with a straight tongue from a straight line. The gauge line of the tongue is tangential to the curve, which commences from the heel of the tongue and terminates at the theoretical nose of the crossing. The tangent at the crossing to the curve lies at the angle of the crossing.

The following definitions and symbols will be used throughout:

Gauge.—The distance between the rails of a track, measured from inside edge to inside edge of rail heads.

Nose of Crossing.—The point of intersection of the gauge-lines, an imaginary point some inches in front of the blunt nose, to which all measurements are referred.

Radius of Crossing.—The radius of the curve of the turnout, springing from a point in advance of the switch.

Divergence.—The distance, at heel of tongue, or virtual heel, from inside edge of stock rail to inside edge of tongue rail, in other words, the clearance between those rails plus the width of the head of the rail.

Inclination-number, or shortly, *Number of Crossing*.—There are three methods of calculating this, see Art. 49; generally the cotangent of the angle of the crossing.

Curve Lead.—The distance from the springing of the curve to nose of crossing, or other end of the curve, measured along the straight. The curve is not utilised throughout.

Switch Lead.—The distance from springing of curve to point of fixed divergence, measured along the straight.

Lead of Crossing.—The distance, measured along the straight, from theoretical nose of crossing to opposite the point of fixed divergence.

The following symbols will be used:

G = gauge.
a = angle of crossing.
I = number of crossing, usually cot a.
l = length of tongue rail up to point of divergence.
D = an ordinate to the curve, not necessarily = G.
d = divergence at fixed point.
$b = \sin^{-1}(d/l)$ = angle of divergence of switch.
$i = l/d$ = inclination number of the switch.
R, R_1, R_2 = radii of curves intersecting the rails.
L′ = curve-lead.
l' = switch-lead.
L = lead of crossing.

In Fig. 8, we have a straight tongue AC, with a switch angle b, and a crossing, the angle of which, at the theoretical nose E, is a, the connecting turnout curve running from C to

E, tangential to the heel of the tongue and to the splice rail of the crossing.

The radius R can be obtained by solution of the triangle D E C, of which we know all three angles and the side D C, in this case equal to the gauge less the divergence at the heel of the tongue. C E is the chord$=2R \sin (a-b)/2$, whence we obtain R.

It is easier to calculate by co-ordinates If O be the origin of the circular curve, the ordinate at the end of the abscissa

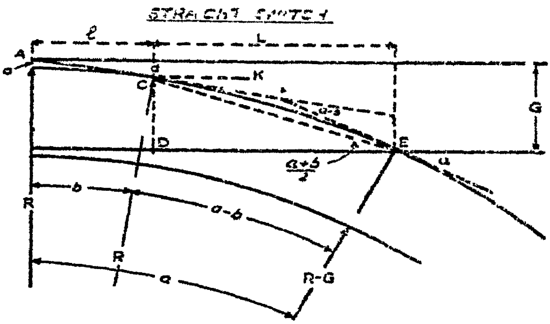


Fig. 8.

OX_1, is X_1C, and the ordinate at X_2 is X_2E. Both X_1 and X_2 are offset from the gauge line by some amount o, unless the tongue is tangential to a curve springing from the gaugeline, and this is rarely the case.

$$D = X_2E \pm o = R \text{ versine } a$$
$$d = X_1C \pm o = R \text{ versine } b$$

The versine is 1 minus the cosine. Seven place tables should be used.

Subtracting, $D-d=R \text{ (vers } a - \text{vers } b) = R (\cos b - \cos a)$

$$R = (D-d)/(\cos b - \cos a). \qquad (1)$$

Now $OX_2 = R \sin a$, and $OX_1 = R \sin b$.

$$\text{The Lead } X_1X_2 \text{ is } R (\sin a - \sin b). \qquad (2)$$

The offset o=D−R vers a, and will only vanish if AC is =R tan b/2, that is, if the virtual length of the tongue, or straight portion of it, is equal to the tangent distance.

The use of these two formulae will give offsets for true laying and maintenance of the turnout curve, at any points desired.

The larger we can make D−d, the larger the radius of the curve, consequently the smaller the gauge of the track, the sharper the curve becomes, with equal switch and crossing angles. If the curve is made to end at the near end of the crossing, where the wing rails are held together and cannot be bent between this point and the theoretical nose, the gauge is narrowed in effect. If the curve is carried on to the far end of the crossing, as is done on one French railway, with suitable adjustments, then the curve radius is increased.

With a smaller switch angle, due to lengthening a straight tongue with the same divergence, cos b becomes greater, and is in the denominator, so that the radius is diminished. On narrow gauges a small switch or crossing angle is not desirable, apart from the danger of derailment of small wheels at the crossing. It is a matter for nice adjustment to divert the train from its path without too much side acceleration and to give the same side acceleration, if possible, throughout the succeeding curve. For military railways it is desirable to avoid cutting of rails as much as possible.

A smaller switch angle increases the lead in Formula (2) because the sine is smaller. Increasing the switch angle reduces the lead, and this may follow from the adoption of a heavier rail for the switch, with the same tongue length. In order to avoid much disturbance of interlocking gear, the same lead may be retained by introducing a short length of straight behind the heel.

If the springing of the curve lies on the gauge line of the straight, as was assumed in Cole's Method, but in reality is seldom the case,

$$G = R \text{ vers } a, \text{ and } R = G/\text{vers } a.$$

The tongue length in order to be tangential to this curve, must be equal to, or less than R tan b/2, the difference being made up by a short length of straight behind the heel up to a virtual heel. Cole's Method, if this condition be fulfilled, gives the longest radius of turnout, for a given crossing and gauge.

It is possible to insert a transition curve, springing from the gauge line of the straight, and tangential both to the heel of the tongue and the crossing. This was examined by the Author in the *Railway Engineer* for December, 1929. The radius of curvature at the theoretical nose of the crossing is 216 G, or 1,188 ft on the 5 ft 6 in gauge. A cubic parabola will not, of course, be symmetrical in both facing and trailing directions The theoretical length of the tongue, in order to be tangential to the curve, will be one third instead of one half of the switch lead. To make the transition curve commence at the heel is not practical.

49.—Switch and Crossing Angles.

Reference has been made to the theoretical length of the tongue. The switch angle is not exactly obtained from the tongue length, because the toe must still retain a certain thickness, as will be explained. In the expression above for the angle of divergence, the thickness at the toe, say ¼ in., should be deducted from *d*.

When selecting a switch angle for adoption, the effect on the vehicle should be considered, and it is usually accepted that a diverging movement of one foot per second is not excessive. We may assume that a speed over turnouts at facing points of 30 miles per hour may be allowed on the 5 ft. 6 in. gauge, with corresponding speeds of 20 miles per hour on the metre gauge, and 15 on narrower gauges. That is to say, a wheel will traverse a distance of 44 ft., 29⅓ ft., and 22 ft. per second respectively.

Allowing a divergence of one foot in these distances gives

switch angles of 1° 18 min., 1° 57 min , and 2° 36 min respectively. If this be conceded, the radii of lead curves should be such that an offset of one foot to chords of the three respective lengths fulfils the relation $C^2 = R$ (see Art 59). The radii corresponding are 1,936 ft. (2° 57 min), 860 ft. (6° 40 min.), and 484 ft. (11° 50 min). Alternatively the speed should allow for an unbalanced cant of two inches.

Crossing Angles—These will vary slightly according to three methods adopted in setting out work in the shops see Fig. 9).

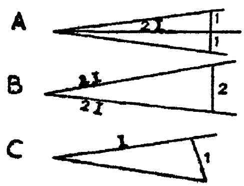


Fig. 9.

A British and United States practice is to make the cotangent of *half* the angle equal to twice the crossing number, or

$$\cot a = 2I$$

This is the easiest way of setting out. The setting out line bisects the V, and the lines joining the theoretical nose to the offsets lie along the gauge lines of the crossing. Any length of point rail is easily set out.

B. This adopts an isosceles triangle making

$$\operatorname{cosec} a/2 = 2I.$$

C, or Cole's method is to make $\cot a = I$, but the point rail may be longer than I feet.

The resulting angles are

Number of Crossing.	Method. A	B	C
12	4° 46′ 19″	4° 46′ 34″	4° 45′ 59″
10	5° 43′ 29″	5° 43′ 55″	5° 42′ 38″
8½	6° 43′ 59″	6° 45′ 6″	6° 42′ 35″

C method, therefore, gives the most acute angle.

50.—Curved Switches.

Tongues are not always straight. They may be partly curved, or wholly curved right up to the toe. In Fig. 10 the straight planed portion extends for 11 ft only, up to the point where the rail head attains the full width of $2\frac{3}{4}$ in. This is the virtual heel. In one switch the planing extends to 20 ft. $7\frac{1}{2}$ in., or 1 in 90, with a switch angle of 0° 38 min. 12 sec. The remainder of the tongue, and the corresponding portion of the opposite stock rail, is curved, in the Figure, to a radius of 1,378 ft., until, beyond the actual heel, ordinary chairs can be got in between the straight rail and the lead rail. The tongue is sprung from the seventh chair to give the necessary gape of $4\frac{1}{2}$ in.

This radius has been calculated to fit a 1 in 12 crossing, by the formulæ already given, but it can be used also with certain crossings of a higher number, by using the formula

$$\text{Radius} = (D-d')/(\cos b' - \cos a')$$

b' is the switch angle at the back heel chair, 6PR, there being added to the angle obtained by divergence the central angle subtended by the arc of curvature. d' is the divergence at the back heel chair from the gauge line, and a' is the angle of crossing to be used instead of the normal one.

The curve will now be a compound curve, the portion over the lead having a smaller radius, with a common tangent at the back heel chair. The lead from this to the theoretical nose of crossing will be,

$$\text{Lead} = (D-d') \cot (a'+b')/2$$

To this must be added the length of the switch to obtain the distance toe of switch to nose of crossing. The springing of the curve will still lie inside the gauge line of the straight, unless the length of planing$=$R $\tan b'/2$ (not $b/2$).

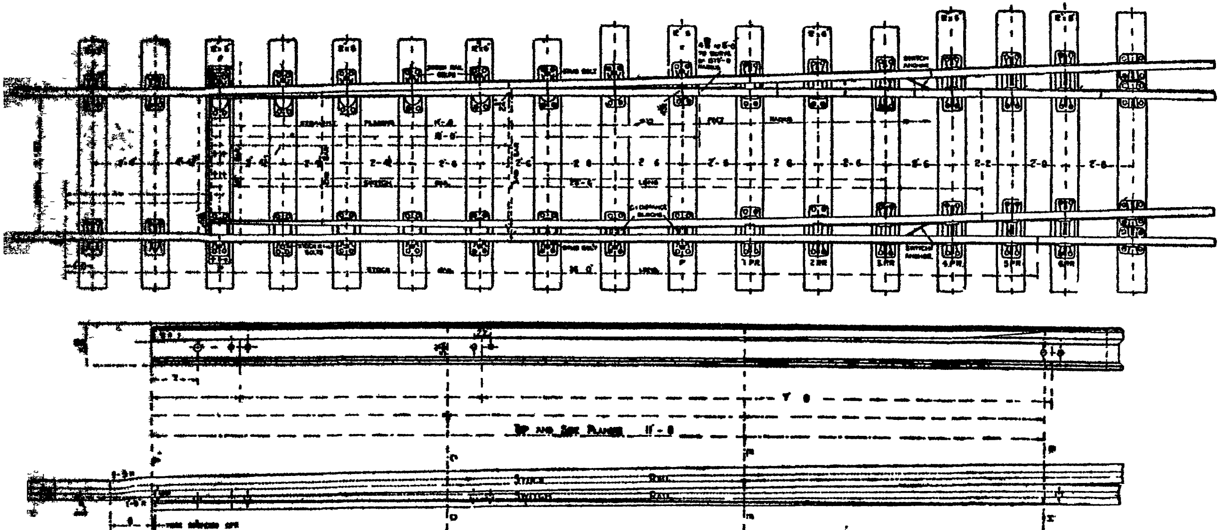
A wholly curved switch is curved from toe to heel in a compound curve, with a common tangent. They have been

STANDARD RAILWAY EQUIPMENT — PERMANENT WAY.

"D" STRAIGHTCUT SWITCHES.

95 R. B.S. RAIL.

PLAN



— PART ELEVATION AND PLAN AT END OF SWITCH (RAILS VERTICAL) —

Fig. 10.

in use for 40 years on the Great Western Railway of England, gradually working up to the longest curved switch, shown diagrammatically in Fig. 11, for use with crossings Nos. 10 to 13. It has a radius from toe to heel of 2,000 ft. With No 13 the radius between the heel and the crossing is 1,600 ft. The springing of the curve at the toe lies 30 ft. 10 in. in advance of the toe, and the offset outside the gauge line is 0.237 ft.

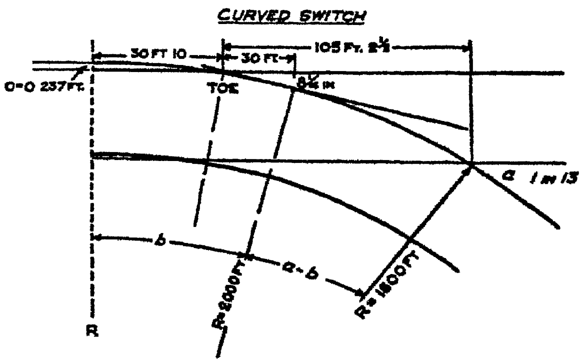


Fig. 11.

On the Est Region of the French National Railways, the curved switch, for use with a 1 in 20 crossing, springs from a point 3 in. outside the gauge line, with a radius of 2,001·445 metres up to the full width of the rail head. The radius of the stock rail opposite is 2,000 metres.

From full rail head width springs a curve of 1,301·445 metres up to a point 2·868 metres beyond the theoretical nose of the crossing. Since the exsecant of this curve is ⅛ in., the throat is widened by this amount. The prolongation of the splice rail does not lie along the gauge line of the corresponding wing rail, which is made tangential to the curve. Thus, the total curve lead is made up of four elements, advanced switch lead, switch planed length, lead to theoretical nose, and lead in rear of the nose. The large radius is obtained by increasing (D—d) as much as possible.

Curved switches are not interchangeable in right and left-hand turnouts, and their use involves the holding in stock of more types of material, but the practice of welding worn crossings *in situ* makes this less of a disadvantage

It is not difficult to plane a curved tongue. After bending, it is sprung to the desired curvature in the opposite direction, is planed on the straight, and, when it is released, assumes the correct curvature

51.—Description of Points.

A set of points (Figs. 10 and 12) consists of a pair of tongue rails, straight or partly or wholly curved, each tapered to fit a stock rail, also straight or curved On the one side the tongue rail is bolted to the main line heel rail, i.e. the lead rail next behind the tongue rail, and the stock rail to the turnout lead rail. On the other side, the tongue rail is bolted to the turnout heel rail, and the stock rail to the main line lead rail. Heel blocks of various designs may be used at the junctions of tongue and heel rails, or the tongue may be held and sprung from a "virtual" heel. We shall call a complete stock rail, and tongue rail, with accessories, a switch. A pair of switches make a set of points, facing or trailing.

The tongue rails are connected together by connecting rods of such a length that, when one tongue rail is pressed against its stock rail, the toe of the other tongue rail makes an adequate gape or clearance, and there is no possible chance of wheel flanges striking the toe of the tongue, and causing a derailment. To the tongues are fastened point rodding, and connections to the locking and detecting gear, each tongue being detected separately, to give warning of running through in a trailing direction. There may also be a connection to a point indicator, and the gauge tie should be noticed. This may be a steel plate on the sleeper.

A single switch may be used, in connection with a ground

disc, to isolate a siding by causing derailment if the signal is not obeyed

The tongue rail slides on one-level or two-level slide chairs, bolted to the stock rail, and supporting it, while the bolts are extended to form studs and support the web of the tongue rail.

A right hand set of points will divert a train to the right, and a left hand set to the left of a person facing the points. In an indent for a tongue rail, or stock rail, or complete switch, the right hand tongue is on the right hand of a person looking from heel to toe, i e. in the opposite direction, and both stock rail and switch corresponding should be so described. The tongues, of course, differ, and the stock rails also. Mistakes may easily occur from a wrong description, and it is better to add a sketch as well.

Points are described as facing or trailing, according as the train, in normal running, passes from toe to heel of the tongue, or vice versa. Usually they fulfil both functions in shunting, and on single lines, but the outermost points of stations on such lines are termed facing points.

The tongue rail has to be movable, and can only be held at some distance behind the toe. It may be loosely fished at the heel through a block to the stock and heel rails, with circular washers on the bolts to prevent over-tightening. It may be held at a "virtual heel," from which it is sprung, or by a hinged heelblock. For support underneath, the tongue rail must depend on slide chairs, on the sleepers. For lateral support, especially necessary since the tongue rail has the function of diverting a heavy train, it has to depend on the stock rail. The A.R.E.A. designs show a reinforcing steel angle, and indeed, a double reinforcement along the tongue. The tongue may be tipped with manganese steel.

Towards the toe, the tongue rail is planed so as to lie as close to the stock rail as possible, but, as it diverges, studs, short and long, have to be introduced to support the web. These must be properly designed, and it is best to secure

them with cotters and split pins, less liable to work loose than bolts and nuts.

The tapering of the toe of the tongue rail is done in two ways. Either it is planed very thin and housed under the stock rail (" undercut,") or the stock rail is " joggled " with a reverse bend, allowing rather more section to be left of the original rail from which the tongue rail was planed.

The stock rail section need not be reduced for B.H. rails (Fig. 10), though little remains of the tongue rail section. But with F.B. sections and their wide flanges, the stock

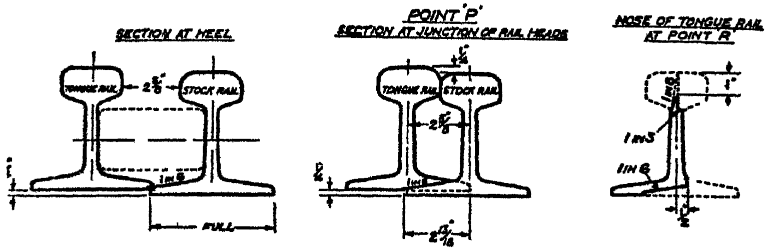


Fig. 12a.

rail also has to be weakened by planing, especially with long straight tongue rails. There is less planing of the stock rail but more of the tongue rail, if the tongue over-rides and rests on the flanges of the stock rail (Fig. 12 and 12A.)

If the rail selected for the tongue rail were machined to the slope of the switch angle, the head and foot (or bottom) would have no web to join them together. Therefore the rail has to be bent, at such a point, and to such an angle, that the web shall be vertical at the toe.

The width of head of a 90R F B. rail is 2⅝ in., and that of the bottom is 5⅜ in., the difference being 2¾ in. Full section in a straight stock and tongue rail, if not over-riding, can only be attained where this clearance is attained. By adopting a B.H. rail any desired clearance can be given, and weakness is reduced to a minimum. German railways have

a rectangular section or a special section with increased thickness of web.

For heavy, fast traffic, the portion of the stock rail in advance of the toe of the tongue rail should be greater than stock rails of switches for slow movements There is the stress of the joint, and a permanent torque, if the stock is vertical, and the rail in advance is tilted. Rail anchors should be used in advance of the stock rail. It is desirable that at least two sleepers be interposed between the joint and the planing of the stock rail flange to accommodate the tongue.

The slope of reduction of flange width should be one and a half times the width. A full length rail should be laid in advance of the stock rail on main track. Drilling of the stock rail for attachment of a locking bar can be avoided by using clip brackets.

The projection of the stock behind the heel of the tongue must take account of the proper fixing of the heel block to both, and of the joint with the heel rail, which will affect the sleeper spacing, and this should be small. There is also the lead to be considered up to the crossing.

Stock rails may well be made of full length rails, projecting well in front of the toe and behind the heel.

The connecting rods must have a vertical pin to allow of a swivelling action, very slight, on account of the two tongue rails not moving precisely parallel to each other. More than two should be provided for long tongues. These rods should be cranked downwards, to avoid hanging couplings and insulation may be necessary.

Slide chairs, sometimes stepped, not only provide the surface for the tongues to slide on, but also support and hold the stock rail, and support the tongue rail through the stock rail studs, except in the first few. These chairs are usually made of steel for F.B. rails, and B.H. rails are, of course, held in cast iron chairs.

A bar may be provided, passing under both stock rails,

connected to the tongue rails to prevent rising under the leverage of a wheel approaching the heel. This also may be insulated.

A "spring tongue" rail is fully fished to the lead rail well behind the "virtual heel," which is held in a fulcrum chair (Fig. 12), so that the leverage of the point rodding may set the tongue rail away from the stock rail to the required "gape." Inner stops can be provided to the slide chairs of such tongues, and thus a certain amount of support can be given, through the connecting rods, to the tongue in action.

The provision of a check rail in advance of the toe of a tongue rail is advocated, but the locking bar, if any, will make this possible on one side only. They are used more often on mountain railways, where curves come right up to the facing points.

52.—Description of Crossings.

Crossings provide the necessary gap for the wheel flanges to pass across the running rails. A V crossing (Fig. 13) is used where only one wheel of a pair needs to cross, such as in a simple turnout or at two of the corners of a diamond (Fig. 23). At the other two corners of the diamond both wheels of a pair cross almost simultaneously, and diamond crossings are used.

In the V crossing the wheel flanges run against the inner edges of the wing rails, whereas in the diamond crossings the flanges run against the same relative running edges. In the V crossing the point rail takes over the load from either wing rail, but in the diamond crossing one wing rail takes over the load from two point rails. The point rail in a V crossing has to have a splice rail, forming the V, but that of the diamond crossing need have none, although shocks will be lessened by fitting a splice check rail, and is longer. In the V crossing the wing rails are splayed to form check rails to the point and splice rails, but in the diamond crossing there is a check rail with this sole function, and on

CROSSING ANGLE 1 IN 12 FOR 90 R RAIL

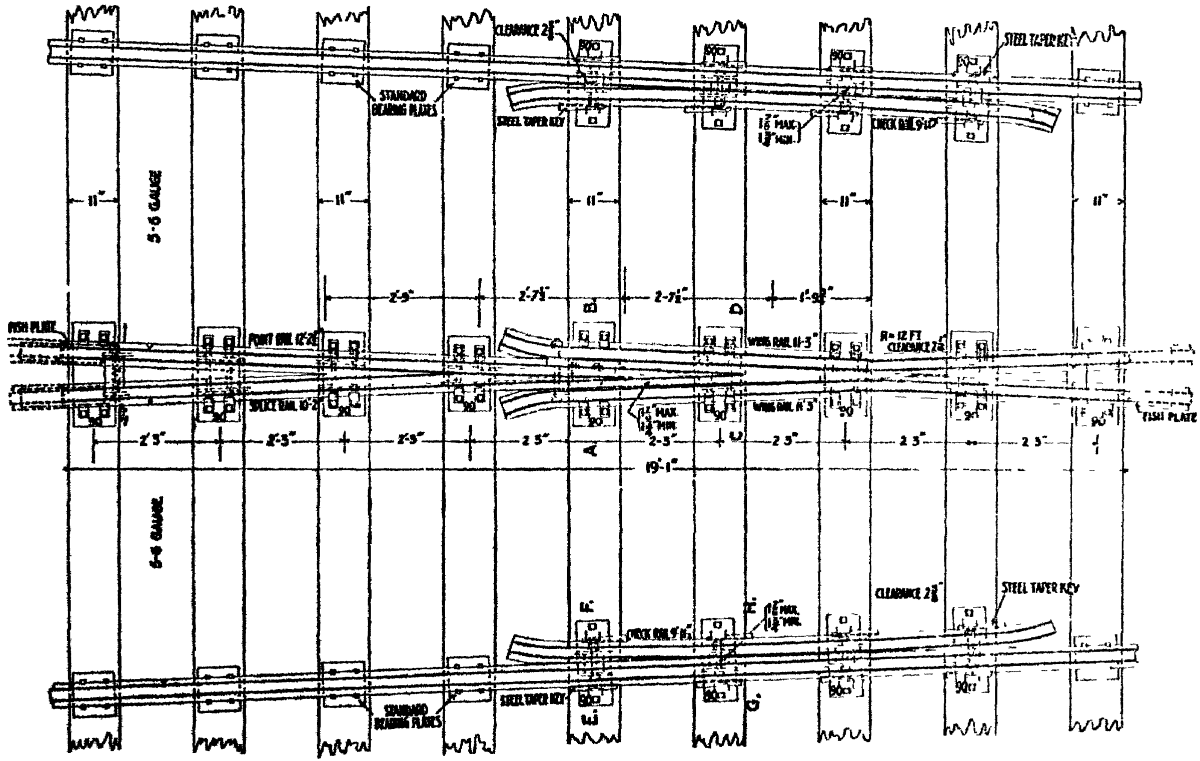
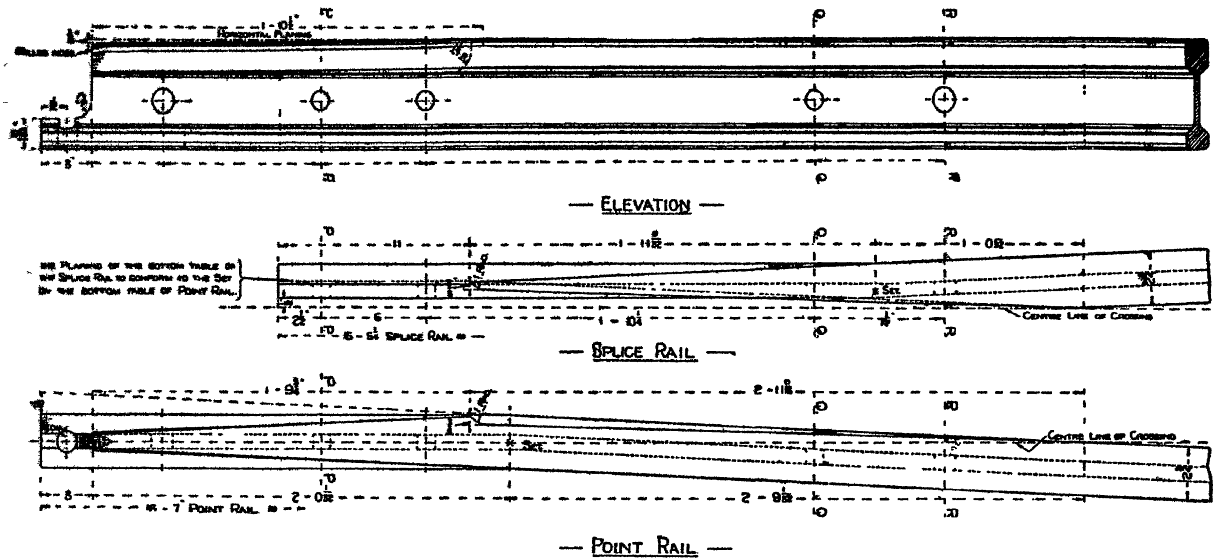


Fig. 13.

STANDARD RAILWAY EQUIPMENT — PERMANENT WAY.

COMMON CROSSINC I IN 12.

95 R. B. S. RAIL.



— Details of Crossing Nose —

Fig. 14.

the Continent, a plate is sometimes bolted to this rail, projecting above it, to act on the outer wheel face, and help to guide the wheel flange past the elbow. The diamond crossing is symmetrical, and the V crossing is not. Compare Figs. 13 and 16.

Where the wing rails of a V crossing, or the wing and check rails of a diamond crossing, approach and diverge again is the throat. The intersection of two thin wires, laid along running edges of the wing rails and point and splice rails respectively, will give the theoretical nose of the crossing (Fig. 7).

Where a V crossing is used, it is necessary also to use a check rail on each of the opposite running rails. This guides the flange of the other wheel of a pair, by pressing on the inner wheel face, and prevents knocks on the nose or even derailment. It may be self-guarded by a block which presses against the outer wheel face for slow traffic only. Diamond crossings, being used in pairs, have a check rail as a component part.

The Ministry of Transport does not permit a flatter angle of diamond than 1 in 8. It being impossible to prevent a certain amount of oscillation in the throat, the nose of one point rail must be in advance of the other. The distance will be G/I, or nearly ·7 ft. on the 5 ft. 6 in. gauge, against ·6 ft. nearly on the 4 ft. 8½ in. gauge. On the 2 ft. 6 in. gauge it would be only 3¾ in. with a 1 in 8 diamond.

The switch diamond (Fig. 16A) is a device for use where the inclination is required to be easier than the prescribed limit, but an ordinary switch has not a sufficiently large switch angle. Such crossings are specially suitable for a curved track or tracks. Half a switch diamond might be used instead of a V crossing, but it would require rodding, detecting and locking.

In building up a crossing, or bolting a check rail to the running rail opposite the V crossing, clearance blocks or

chairs, and spherical washers have to be used. The appropriate clearances are given in Art. 54, but at the throat $\frac{1}{4}$ in. or more has to be allowed. The ends of check rails, and the check portions of V crossing wing rails, are gently flared, so as to draw the wheel flanges gradually into a good position.

If the turnout curve is so sharp that widening of gauge is necessary, the check rail clearance blocks on the turnout side should be wider by the amount of widening Otherwise there will be a knock at the throat. The *net* dimension from nose to check rail will remain the same.

The desirable elimination of the gap at the crossing has been attained by a device called a "spring rail crossing" in the U.S.A., better described as a continuous crossing. They are not allowed for crossings of numbers under 6. The check rail portion of the wing rail on the turnout side is utilised, and lies along the V, so that a main line train has no gap to cross. It is held against the V by two strong springs. The wheel flanges approaching on the turnout, in a facing or trailing direction, have to force their way through by pushing the wing aside against the springs up to stops, which allow the necessary clearance. There is, therefore, a considerable wear, and the check rail is much worn also. There is a tendency for the flared end to rise, as the wing takes the load, and this has to be checked. Crossings of this type can only be used for the turnout for which they have been designed. Their use will be justified if three quarters of the movement is over the main line.

On narrow gauge railways, a cast crossing may be adopted instead of a built up crossing. Some are made reversible, but the fixing device usually suffers from the attempt to lengthen the life by reversing.

The difficulty of designing satisfactory switches with wide based F.B. rails applies to V, or common, crossings also. It is not possible, without cutting the foot, to give even a $1\frac{7}{8}$ in. clearance with rails heavier than 55 R, so that wing rails are

very much weakened at the throat, and tend to tilt inwards under the load. As the wings diverge again from the throat, more metal can be left, but there should be no sudden change of section. In order to leave a sufficient amount of metal in the nose, the wings opposite the nose have to be weakened, and this continues up to and beyond the point, where the load is transferred. Along the check portion of the wing rail this does not matter so much, nor does it matter in the opposite check rail, because any overturning movement is against the unweakened part of the flange, and the check rails carry no load. In the U S.A., and on the Continent, under very heavy loads, F.B. rails are used with apparent efficiency. In time, however, loosening and wear lead to weakness, and earlier destruction of the crossing The close coupling of trains causes a great strain on the crossing bolts when the turnout is taken.

It is necessary to visualise what happens, when a wheel passes the crossing, in a facing direction. Up to the throat, the wheel is travelling on the wing rail, just as on an ordinary rail, possibly with the flange hard up against the side of the head, if the check rail is worn. From the throat onwards the wing rail recedes, and the bearing, assuming normal wheel treads, also recedes, so that the flange is dropping because of the coning of the wheels. There comes a point where the point rail takes the load, it may be at the greatest wheel diameter, close to the wheel flange, and from this point onwards the wheel runs as on any other rail. Therefore, between the throat and the point of bearing on the point rail, the wing rail, and at the point of bearing the nose should be as strong as possible.

Worn wheel treads with worn flanges tend to take a bearing earlier on the point rail. A worn crossing will be found to have deeply scored wing rails for about 2 ft. on each side of the nose, which is bright almost to the end, showing that transfer is taking place in advance of the right spot.

The wing may be ramped, or "glut" ramped, so that the flange takes a bearing, or made of heat treated or manganese steel to extend its life, but the modern practice of welding makes these devices less necessary.

The point rail in a built-up crossing extends to the nose, and should be firmly held. In one design a projection is machined in advance of the nose at the foot, with a hole through which the nose can be bolted to the sleeper by a fang bolt.

The point rail has to be set (Fig. 14), so that the web lies vertically under the nose, as in the tongue rail. It is machined, so that the running edge may be continued along the edge of the V. The end of the nose is machined down so as to escape the transfer of the load, and rounded, so as not to form a sharp point and invite the flanges to strike it. The radius of rounding is about half an inch. The inclination of the nose below the level of the wing rails depends on the number of the crossing, and point of transfer of the load, where the nose must be up to wing rail level. It will be necessary to twist the point rail to link it to tilted rails beyond.

The intersection of the edges of the V should be marked during manufacture on every crossing, for the rounded nose does not give the true intersection. The design should show the position of this theoretical nose (see Fig. 7).

The point rail carries the load on one track, and a splice rail completes the other track. This also has to be set and machined like a tongue rail, and must lie against the point rail, to which it is fished, usually by four bolts, but two rivets may be substituted for the inside bolts. Their function is to take shear. In some designs the end of the splice rail is housed in the head of the point rail. The housing may extend for ½ in. multiplied by the number of crossing. The position of the splice should take account of the clearance block behind the nose, and adequate sleeper support. The splice rail also must be twisted to link with tilted rails beyond.

The question of length of wing rails is important. If they are long and straight in advance of the nose, they reduce the radius of the turnout curve, and add to the weight, but thus increase the inertia and resistance to shock. Behind the nose the check rail portion need only be long enough to lead in wheels trailing, with sufficient flare, but they should extend over at least two sleepers behind the nose, exclusive of flare. In some layouts the wing rails may be extended as check rails to another crossing, so that flaring will be unnecessary.

If B.H. rails are used the chairs hold the crossing together, but for F.B. rails the clearance blocks should be wide, say 6 in., and double bolted in every case. Every care must be taken in design to see that these blocks do not tend to tilt the rails, when the load comes on, and give all possible support. Chairs and blocks must allow for rail wear, and not become subject to be struck by wheel flanges. It is not sufficient to allow only the maximum shown in Art. 54, especially on either side of the nose.

The clearance blocks, which should be well fitted, will vary a good deal with their positions in the crossing. The bolts used should be at least 1 in. in diameter, preferably turned and fitted. Washers should fit the upper and lower fishing planes, and be sufficiently thick outside to allow of tightening of the bolts by spanners applied normally and not at an angle. The sides of the webs of R series F.B. rails being tapered, taper or spherical (Fig. 15) or bevel lock washers are necessary.

A F.B. crossing has to have special chairs, usually of steel plate, with lugs pressed up, or riveted on, and steel taper keys are used to secure the flat bottoms. The B.H. crossing is much stronger all round, and less liable to "chatter." Twin hook plates are adjustable for any crossing angle, and are each held by five long spikes. The whole crossing in the vicinity of the throat is preferably riveted to one steel plate, but the riveting of some flanges to this plate is

not easy to arrange. The rivets should not be countersunk, or they are sure to work loose.

Ramping of the wing rails, although it relieves the nose, causes a certain complication by necessitating packing, or a double step crossing chair, and there will be difficulty in fitting the clearance blocks properly. It may cause lateral bogie oscillation.

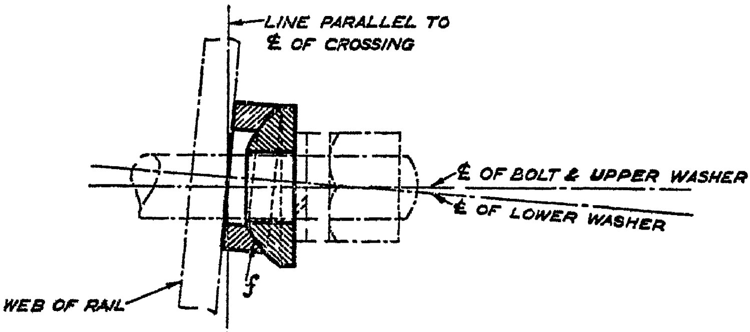
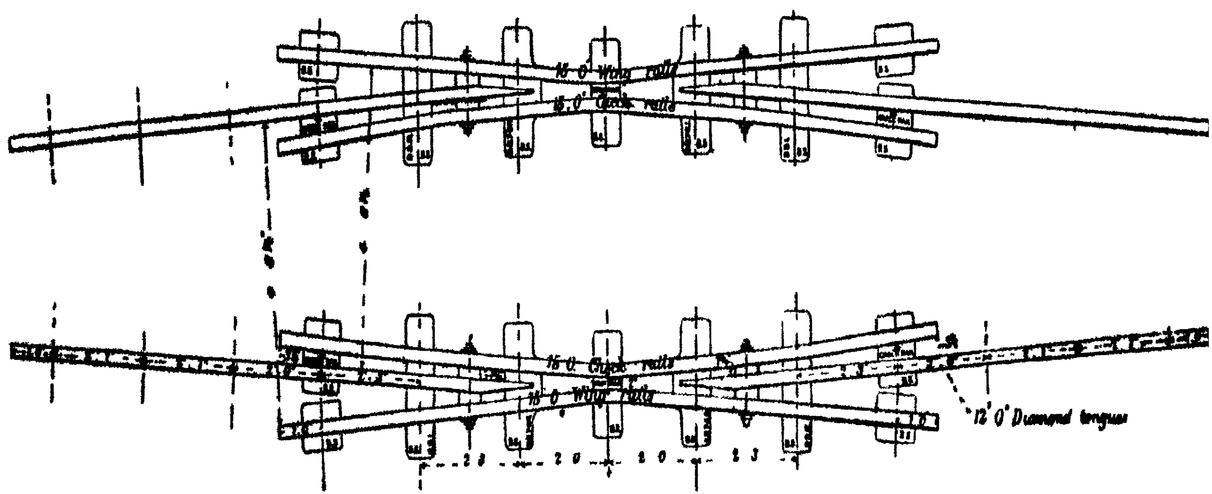


Fig. 15.

The check rails may be considered parts of a V crossing, just as they are in a diamond crossing. As they are subject to abrasion, they should be heat-treated. If they are held by clamps the wedges should be driven on the inner side of the check rail. Adjustment of clearance must be possible. The ends are flared about 1 in 24, but by altering check chair clearances a gradual lead in of the wheels, at 1 in 60 or better, should be given. The critical point where abrasion is worst is at a clearance of $2\frac{1}{2}$ in. Clearances should be greater all round on the turnout side.

Check rails should project about three-fifths of the length in advance of the nose, and be carried by six chairs on single, and five on double track. On sharp turnouts, however, check rails may have to be extended to the heel of the tongue rail. They may stand $\frac{3}{8}$ in. to $\frac{1}{2}$ in. higher than the

Fig. 16



1 in 8 Diamond Crossing

SWITCH DIAMOND CROSSING
(1 IN 8)

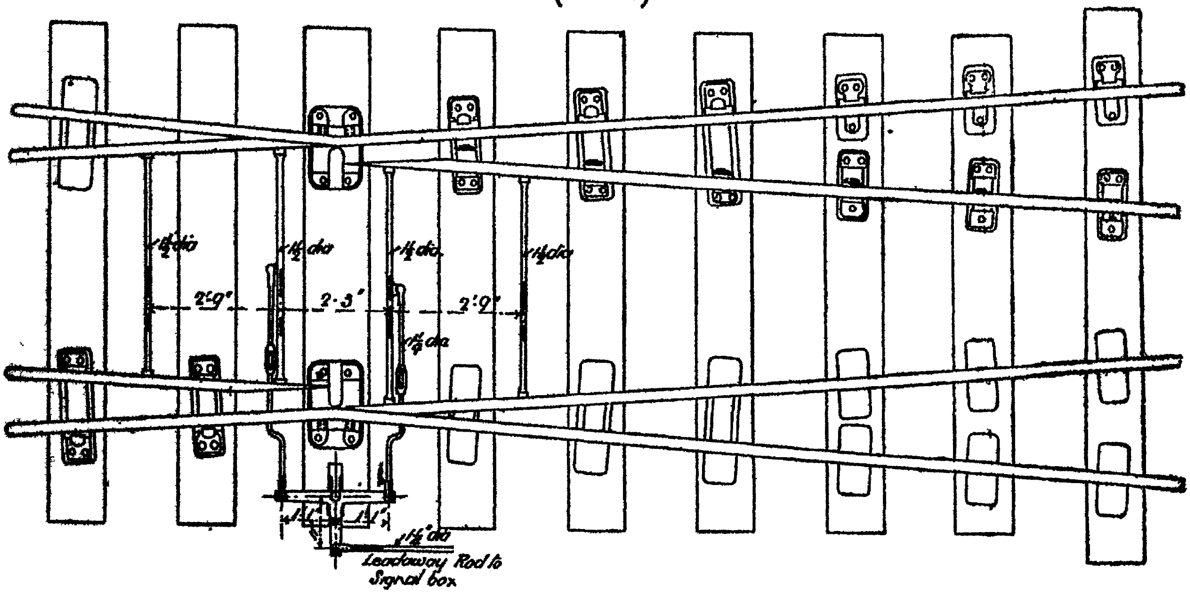


FIG. 16a

running rail, especially if Bissell trucks are used on the locomotives.

In a diamond crossing (Fig. 16) the security of fixing of the point rail is very important. The length of a point rail is limited usually by consideration of layout, since the heel of a tongue rail, or the wing rail of a V crossing, may have to be bolted to it. Considerations of layout also should fix the length of wing rail and check rail, and they should not really be made to a fixed pattern. A wing rail for a slip road may even be machined to form a stockrail. Check rails will be flared at the ends, but wing rails will not, since they are invariably bolted to another rail. In France a check rail raised guard, bolted at the angle, is considered to be indispensable. The special chairs will, of course, differ entirely from those of a V crossing. A switch diamond is shown in Fig. 16A.

53.—Lengths of Switches and Crossings.

The whole turnout should be designed to require the minimum amount of cutting of rails, the avoidance of short closers, and the spacing of sleepers to the best advantage. The same layout, however, will not suit an ordinary crossover, a slip road, and a steep gathering line, even if the same switch and crossing be used. It may be necessary to shorten stock rails and even crossings.

The practice of cutting straight tongue rails "by the yard," 9, 12, 15 ft. and so on in length, is out of date, and the lengths have been much increased in order to obtain a small switch angle. The straight planing of partly curved switches also has been increased. The British Great Western Railway uses a straight 32 ft. tongue with a No. 20 crossing and a radius of 3,698 ft. Partly curved tongues on British Railways run up to a length of 33 ft. 6 in. German Railways have a 49 ft. switch, which with a No. 18·5 crossing gives a radius of 3,937 ft. One French Railway uses a 14-metre tongue, sprung from a 24 metre rail, with a No. 20 crossing.

Short tongues are liable to tip up, so that the length should not be shorter than the distance between any two following wheels. Long tongues, on the other hand, become very slender towards the toe.

It has been suggested that the total length of crossing should not exceed R/90, but this cannot suit radii in modern practice. On one French railway the No. 20 crossing is 27 ft. long. Crossings and wing rails are usually made symmetrical and interchangeable in turnouts of either hand.

4.—Clearances.

When designing points and crossings, the thickness of tyre flange, and the distance between inner faces of wheels must be borne in mind. This is specially necessary on the turnout side, because the curve tends to throw the leading wheels out of centre, while the rest of the locomotive wheels may take up different positions, and hardly any wheels remain normal to the gauge.

The following Table gives details for India :

	Gauge. 5′ 6″		Metre.		2′ 6″	
	ft.	ins.	ft	ins.	ft.	ins.
Distance between wheels	5	3	3	$0\frac{5}{8}$	2	$3\frac{1}{2}$
Maximum thickness of flange of tyre . .		$1\frac{1}{8}$		$1\frac{1}{8}$		$\frac{15}{16}$
Minimum thickness of flange of tyre		$\frac{5}{8}$		$\frac{5}{8}$		$\frac{1}{2}$
Maximum distance, inner wheel face to outside of flange	5	$4\frac{1}{8}$	3	$1\frac{3}{4}$	2	$4\frac{7}{16}$
Minimum distance, inner wheel face to outside of flange	5	$3\frac{5}{8}$	3	$1\frac{1}{4}$	2	4
Difference between gauge and maximum distance		$1\frac{7}{8}$		$1\frac{5}{8}$		$\frac{9}{16}$
Difference between gauge and minimum distance		$2\frac{3}{8}$		$2\frac{1}{8}$		2
Maximum clearance, heel of tongue, check or wing rail opposite nose		$1\frac{7}{8}$		$1\frac{3}{4}$		$1\frac{3}{4}$
Minimum clearance, do. do.		$1\frac{3}{4}$		$1\frac{5}{8}$		$1\frac{5}{8}$
Minimum space below rail level for wheel flange		$1\frac{1}{2}$		$1\frac{3}{8}$		$1\frac{1}{4}$
Minimum clearance at toe of open switch .		$4\frac{1}{2}$		4		$3\frac{1}{2}$

Thus, if the wheel flanges are new, and the inner side of the flange is bearing against a worn check rail, the other flange is just grazing the nose of the crossing. If the flange of one wheel is bearing against one stock rail, the inner edge of the opposite flange is just grazing the opposite tongue rail at the heel. If the wheel flanges are worn to the full permissible extent, and the outer edge of the flange is bearing against the running rail opposite the crossing, the wing rail of the crossing has to deflect the wheels by the difference between the clearance (unworn) and 2⅜ in., 2⅛ in., and 2 in. respectively, or by about half an inch in any case. In order to lead the wheel in without undue shock, and bend the wing rail to a curve, the clearance at the throat of a V crossing is made greater than the normal. This is specially necessary for crossings of low number. This leading in without undue shock has to be considered in the flaring of check rails and of the check rail portion of a wing rail in V crossings. If the wheels are worn, and one flange is bearing to the full extent allowable, against a stock rail, the inner end of the opposite flange will rub against the heel of the tongue rail. The heel is loosely fished, as a rule, to permit of pivoting freely, so that not only does the tongue rail tend to become further loosened, but also receives a violent blow, if the switch is passed through in a trailing direction.

Several devices have been proposed for the better securing of the heel. These include hinge, fulcrum blocks, and the *lengthening and springing of the tongue rail, so as to bring* the actual heel behind the point of fixed divergence.

55.—Crossing Sleepers and Spacing.

Crossing sleepers are of larger section than ordinary sleepers, being 12 in. by 6 in. in British and French practice. In some layouts 25 ft. and 26½ ft. sleepers are used.

In Fig. 7, 70 special sleepers are required for a 21 ft. tongue, and 1 in 12 crossing. In the A.R.E.A. turnout to a

1 in 20 crossing with a 30 ft. tongue, there are 219 timbers, including 53 pieces 21 ft. 6 in. long. The content is 1,266 cub. ft. The use of single broad and strong sleepers demands some thought in arranging the spacing. Steel sleepers are used on the Continent, and should have a greater use.

The spacing of sleepers must take into account the expansion intervals, but most designs do not show the necessary ¼ in. at joints. The Indian Standards Office and the A.R.E.A. recognise one weakness by spacing sleepers closely just behind the planning of the tongue rail. The spacing of sleepers under the crossing in Fig. 7 averages 2 ft., and sleepers near the crossing are skewed to half the angle of crossing. Rail anchors should be used freely, possibly against every third sleeper of the lead curves, and they are especially necessary with spring crossings.

The superelevation of the turnout curve is even more important than on ordinary curves. It is possible to countersink the inner rail in the crossing sleepers, but only by weakening them. To lay the sleepers to a cross slope is the best method. Taking a right-hand turnout and assuming the sleepers to be laid to a slope of 1 in 40, with a standard gauge of about 60 in. centre to centre of rails, the superelevation of the left lead rail is 1½ in. at the crossing. The right hand straight rail will then have the table 1½ in. above that of the right turnout rail, and the left straight rail 3 in. higher. The crossing therefore must be raised 1½ in. more, on bearing plates or chairs, to be level with the left hand straight rail, and this will give the crossing 3 in. of superelevation above the right hand turnout rail. The difference of 1½ in. can be run up along the right hand straight, and the left hand turnout rail, starting from the tongue planing in each switch, by using chairs or bearing plates gradually increasing in thickness by $\frac{1}{16}$ in. to 1½ in. This method is used on the L.M.S. with great benefit and allows of an increase of speed through the turnout curve at junctions, although it is not of so much use in facing

crossovers, leading into a passing siding. Transition curves are interpolated between the V crossing and the diamond crossing of the adjoining track.

56.—Turnout from Curved Track.

Cases of this sort will occur chiefly (although not always) in difficult country, where the main line is curved. There are two main problems:

(*a*) Curves of contrary flexure, where one is a right-handed and the other a left-handed curve. (*b*) Curves of similar flexure, where both curves turn in the same direction. There are two cases of this problem, one where the new curve is of greater radius, requiring a crossing on the outer rail, the other where the new curve is of smaller radius, requiring a crossing on the inner rail, but one demonstration serves both. The former is used for preference on the L.M.S. and stepped chairs are useful to give cant.

With curves of contrary flexures the curve lead will be shortened, and with curves of similar flexures will be lengthened, compared to the curve lead of a turnout from the straight. This is, however, largely compensated for by a shortening and lengthening of the switch lead in the respective cases, so that the lead is of nearly the same length. The length of switch lead must be considered when selecting the length of tongue, which should be shorter for curves of contrary than for curves of similar flexure.

There are in these problems three variables (two curve-radii and the number of the crossing), two of which must be assumed.

It is not worth while to examine these cases in detail. The Inspector has not the means to adjust the switch, by bending the stock rail to the curve while leaving the tongue straight, unless he can find or be provided with slide chairs and stops to suit. The design will have to be a workshop job. At the same time he may have to use standard switches in an

emergency. He can interpolate a length of straight, the length of the stock rail or the whole length of turnout from a straight track, and then slew part of the original curved track to a curve of smaller radius, corresponding to the central angle of the arc and to the shorter length of the arc.

Calculations in former Editions have assumed that the curves of contrary and similar flexures have common tangents, and that the Inspector will have in stock switches and crossings of such numbers that any turnout curve can be fitted in. This is not a practical assumption. A "split lead" with curves of equal radii turning out of a straight track can be arranged with standard switches. Equations (1) and (2) may be used, D being half the gauge, and a half the angle of crossing used, since it will lie symmetrically. The equations can be used to design special switches, also to determine where and how the crossing will lie with curves of unequal radii.

57.—Laying Points and Crossings.

Although the Inspector should be able to plan a layout with standard switches and crossings, facing point layouts require careful working out with economy in cutting rails. It is of advantage to have the whole turnout manufactured to correct dimensions in a workshop, where the rails can be cut, drilled for fish and other bolts and marked, ready for laying at the site.

The material, loaded into wagons so that it can be dealt with in order, should be accompanied by a crane, which may also be capable of moving the wagons. The crane may be mounted on a caterpillar track and move on the formation. The wagons should be placed on a siding close by, so that the material can be slung across without too much swinging of the crane. With crane equipment not only is much time saved, but the gang can be reduced to about twelve. Unloading crossings by hand is a difficult business.

If the Inspector is not furnished with a plan, he should

prepare a dimensioned sketch from standard plans. The exact position of the nose of the crossing must be shown by reference to some fixed mark, a nail in a well-driven peg, for example, but not where the crossing will come and necessitate the reference being lost. If main line rails are to be cut, in advance of the stock rails and behind the crossing, this and the drilling must be done beforehand. If the railway is being first laid, and sidings are being put in behind railhead, this will certainly be necessary.

The line being broken, the rails and old sleepers are removed, and new sleepers slung by the crane, to be placed in approximate positions. The crossing is slung into exact position, then the straight rails and the switches so that they can be linked. If the sleeper spacing has not been marked in the workshop, the switches and rails must now be marked, and the sleepers brought into position. They should then be brought to the correct lateral position, according to saw marks, over which a logline is stretched. These marks may be inside or outside a straight rail. The straight on the crossing side is then carefully fastened down, and only when the alignment of this is satisfactory should the other straight rail be fastened to the sleepers. Gauge should be exact, unless no bearing plates are being used between switches and the crossing, in which the rails take a slight tilt inwards by compression of the timbers.

The turnout lead rails can then be dealt with. The curve may be checked by co-ordinates, found by calculation, or by versines from a chord. The stock rail on the turnout side may have to be set slightly by the jimcrow at the end. Connecting rods are then fitted between the switches, and the other connections turned over to the Signal Fitter. The check rail is bolted or clamped.

CHAPTER V

CALCULATIONS

58.—Estimation of Speed.

THE speed of a train can be ascertained by timing between mile or quarter-mile posts, or evenly spaced telegraph posts, and by calculation. A simple method is to count the beats of the wheels at the joints, provided that the normal length of the rails is known to the Inspector not to vary, for a number of seconds equal to two-thirds of the rail length in feet. The number of the beats will equal the speed in m p.h.

A train travelling at 60 m.p.h. over 30 ft. rails will pass over 176 joints in a minute, neglecting 44 in. of expansion intervals. Sixty beats will be counted in 20·454, say 20 seconds. Thirty beats will be counted in this time at 30 m.p.h. For other lengths of rail L, the formula is L $\times$ 20·454/30.

For long rails, halve the time and double the number of beats. Bogies will cause a double beat, the second of which is disregarded.

Evidence may be required of the speed of a train from an Inspector standing beside the track. Similar formulæ can be worked out for passenger and goods trains by the average lengths of coaches or wagons.

59.—Circular Curves.

A circular curve may be defined by its radius (R) expressed in feet, or metres or chains (the 66-ft. chain of 100 links in Britain, the 100-ft. chain in India or the United States, or the 20 or 30 metre chain elsewhere). It may also be defined by the angle of deflexion, or degrees subtended at the centre by

an arc of one chain in length In some textbooks the chord of one chain is prescribed, but the length of a chord is not proportional to the degree of a curve. A length of arc equal to the radius subtends 57·2958 degrees at the centre.

A one-degree (1°) curve has a radius of 5729·58 ft. for an arc of 100 ft., a 2° curve has half this radius and so on. For chains of other lengths multiply the length of chain by 57·2958 to obtain the radius of 1° curve.

The older railways adopted radii of so many chains, and the central angle subtended by a chain can be determined by dividing the appropriate figure by the actual radius in feet.

The exact length of the circular curve is obtained from the total deflexion of the two tangents divided by the degree of the curve and multiplied by the length of the chain. With a tangent deflexion of 22° and a 2° curve, the length will be 1,100 feet, along the centre line of the track.

A circular curve can be laid out by offsets from a tangent. The formula, with degree curves, for a given abscissa or distance measured along the tangent, is R $\sin a$ (central angle), and for the ordinate or offset, at right angles to and at the end of the abscissa, is $R(1-\cos a)=R$ versin a (see Art. 48).

Another method of setting out is shown in Fig. 17. The final and last offsets are one-half of the normal offset for the length of chord, not the same at both ends. The offset is not measured at right angles to the abscissa, but to the end of the chain, moved over to lie along a chord.

Rule.—To find O, the full offset for a chord of 66 ft., divide 4356 by the radius R; for a chord of one chain of 100 ft. divide 10,000 by R.

Proof.—By similar triangles, $O/C = C/R$. $O = C^2/R$. $O = 4{,}356/R$, or $10{,}000/R$.

To obtain the degree of a curve, stretch a string 61 ft. 9½ in. long to meet the inside edge of the curved rails at the ends of the string. Measure with a foot rule in inches the versine or distance from the middle of the string to the rail.

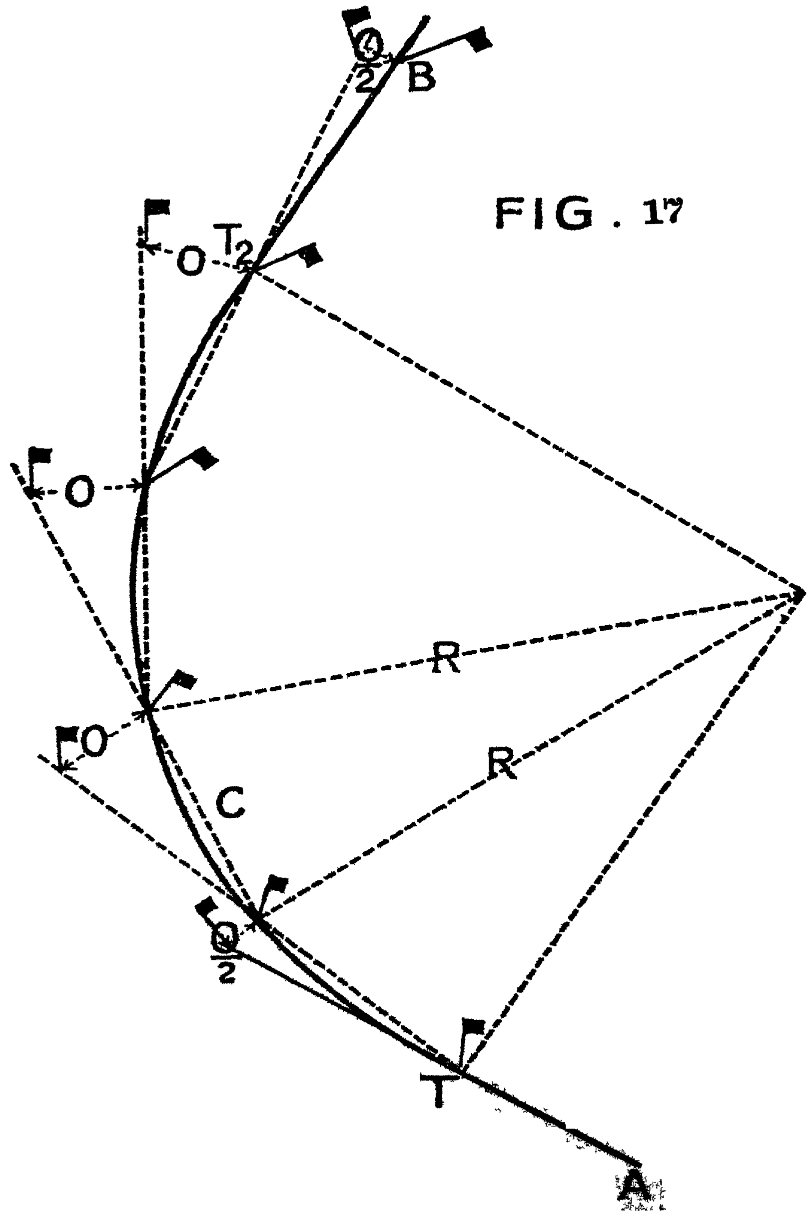


FIG. 17

The accurate formula is $v = R$ vers a, a being the central angle subtended by a chain of 100 ft , but a close approximation is given by $v = 3\,C/2\,R$ where v is the versine, C the length of chord (it may be a rail length which has to be bent). This formula becomes too inaccurate for long rails and for sharp curves.

To bend a rail to a curve, a platform of sleepers is laid, and the curve of the rail marked on it. The rail is placed tangential to this curve, the jim-crow or bender is applied at the end of the rail and a slight pinch is given by turning the screw. A chalk mark is made opposite the screw, and the bender moved along until one jaw is opposite the mark. Another pinch is given and the process is repeated until the whole rail is bent. A good deal of judgment is required to assess the amount of the pinches. If many rails are to be bent, it is best to purchase a special bending machine. There appears to be no advantage in bending rails to fit curves of less than 10° of curvature. The rails can be sprung and held by the fastenings, provided that there is sufficient ballast or soil thrown in to prevent lateral movement.

60.—Rail Joints on Curves.

If all the rails are of the same length, the inner rail joint on a curve will attain an advance or lead over the outer rail joint, and in the aggregate the amount may become considerable. If the joints are supported or "staggered" a slight amount of lead may not matter, but if suspended joints are to be kept as square as possible, then the amount of the lead requires calculation.

If L be the standard length of the rail plus the expansion interval, the lead or advance at the joint of the inner rail is $(R + G'/2)\ L/\ (R - G'/2) = G'L/R$, exactly. $R =$ the radius of the curve, and $G' =$ the track gauge, plus any widening of gauge, plus the width of head of the rail ; the advance, of course, occurs at the centre of the rail head. An

approximate calculation, without any widening of gauge, is one inch per degree of curve per 100 ft. of curve on the standard gauge, or 1·15 in. on the 5 ft. 6 in. and 0·7 in. on the metre gauge. See Table for examples. For the total advance multiply the above by the central angle of the curves.

Advance of Inner Rail in Inches.

Gauge.	Centre to centre of rails. in.	Length of rail. ft.	Curve Radius ft. 2865.	8432.	716
5′ 6″	68 75	36	0·8	1·7	3·4
5′ 3″	65·75	45	1 0	2·0	4·0
Standard	59·25	45	0 9	1·8	3·6
3′ 6″	44 25	36	0·6	1·1	2 2
Metre	41·75	36	0·5	1·05	2·1
2′ 6″	31·75	30	0·3	0 54	1·1
2′	25·5	30	0·27	0·53	1·06

The advance is proportional to length of rail, and to distance centre to centre of rails, and inversely proportional to radius.

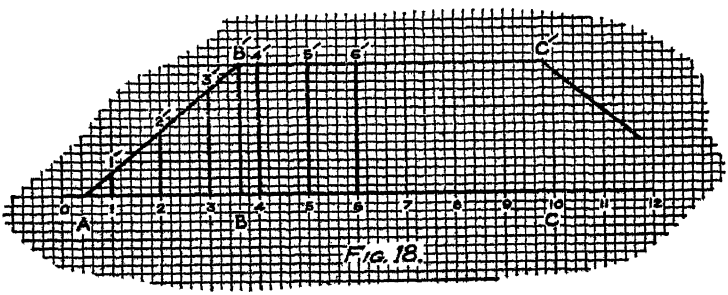


FIG. 18.

On turnout curves, the calculated radius is that of the gauge line of the outer rail. To this must be added half the width of rail table. The radius of the inner rail, for purposes of calculating the advance, will be less by the widening, if any, and the distance centre to centre of rails.

Fig. 18 shows a graphical method of ascertaining the advance of rail joints on both transition and circular curves. It is due to Mons. [illegible] of the Nord Railway, and was described

by the Author in the Railway Engineer for October, 1930. Rail lengths are plotted along the baseline, and 01, 12, etc., are the joint advances for one rail length. The circular curve extends from B to C. AB is the length of transition curve, the second commencing at C. BB′ is any convenient unit.

The advance at joint 2 will bear a simple proportion (area) A22′ to 44′ 56 (area). The advance along the whole transition will thus be the area ABB′, half what it would be on an equal length of circular curve.

The advance of the inner rail may be adjusted on curves of very large radius by sorting the rails so that those slightly longer are laid on the outside. The advance may be allowed to accumulate until the advance becomes equal to half the distance between the two central boltholes in the fishplate, say 4½ in., but this causes cutting and a new bolthole must be drilled. Taking all factors into account, including string lining and the ultimate transposing of outer rails after side wear with inner rails, the advance may be allowed to accumulate from the centre right out to the straights, and be there adjusted by cut rails. The sleepers should be laid radial to the curve, but the bearing plates will not necessarily come on to the middle line of the sleeper. If the joints fall over three sleepers, experience shows good and quiet running. The sleeper spacing will be different for each rail, but this is capable of calculation beforehand with a little study.

61.—Widening on Curves.

This is determined by Roy's Method, which obviates drawing a curve of very long radius and a relatively short wheelbase, to the same scale, and determining the offsets of the wheel flanges to the curve by minute measurement. The principle depends on the fact that if the scale adopted for the wheelbase be 1/n, say 1/40 for a locomotive wheelbase of about 18 ft., the scale for the curve radius must be

1/1600, or $1/n^2$. It may be desired to reduce the tyre thickness to half scale. In that case, the other two scales must be reduced to one half, i.e. 1/80 and 1/3200.

It is not necessary to draw the gauge lines of both rails at the normal gauge distance apart. The second or inner line need only be spaced apart by the dimension of the total clearance between gauge and wheel flanges, $\frac{5}{8}$ in. with British normal flanges. The point of contact between leading wheel flange and rail will be in advance of the centre of the wheel, from which the "rigid wheelbase" is usually measured in locomotive drawings. The angularity of the driving wheelbase must also be determined (see Art. 15). Only if the inner side of any flange touches the second inner line, should the gauge be widened. The flange thickness is sometimes varied on the driving wheels.

There remains the determination of the position of the leading bogie wheels or the wheel of a Bissell truck, seldom used. The line of the wheelbase is continued to, and it may be in advance of, the bogie centre, if it is not pivoted, or to the point of contact of the truck wheel. The offset to the curve gives the amount of the "play."

If the positions of the wheelbase and flanges are traced on a piece of tracing cloth, or transparent celluloid, this may be placed at different positions on the plan of a turnout, drawn according to these principles, and the points where most wear can be expected will be disclosed. The action of a check rail to a curve or opposite the nose of a crossing can be studied similarly.

62. Cant or Superelevation.

When a vehicle is running on a curve, its tendency to continue moving in a straight line is resisted, and the vehicle is induced to keep to the curved track, by the centripetal force impressed on the outer rail by the flange of the outer leading wheel. The centripetal force is the reaction at rail level to

the centrifugal force, which acts on the vehicle at right angles *to the direction of its motion and through its centre of gravity.* The higher the speed and the sharper the curve, the larger the centrifugal force becomes, and if no superelevation were given to the track, the vehicle might overturn with the outer rail as a hinge. To distribute the weight evenly over all the wheels the superelevation should bear the same ratio to the distance centre to centre of the rails as the centrifugal force bears to the weight. That is to say, the resultant of the centrifugal force and the weight in the parallelogram of forces should cut the plane of the two rail heads in the centre of the track.

The formula for the centrifugal force is $W V^2/gR$, where g is the accelerative effect of gravity, 32·2 ft. per second, and the other symbols (V in feet per second and R in feet) are self-expressive. If E be the required cant in feet.

$$E/G' = (WV^2/gR)\ W = V^2/gR$$
$$\text{and}\quad E = G'\ V^2/gR = G'V^2/32{\cdot}2\ R$$

It is more convenient to determine E in inches, and to substitute V in miles per hour.

Then $E = 12\ G'\ V^2/32{\cdot}2\ R \times 5280/3600 = 0{\cdot}8\ G'V^2/R$

G' is the gauge plus width of one rail head, that is the distance centre to centre of rails.

The centrifugal force may be added to or diminished by pressure of the wind blowing, respectively, from the inside or the outside of the curve. The total wind pressure is the product of the pressure in lb. per ft. over the surface presented by the length of the body multiplied by the height to the eaves, and is divided between the two axles of a four-wheeled vehicle or the two bogie bolsters.

The amount of cant determined by the usual formula cannot be correct both for fast passenger trains and for slow goods trains. The slow train imposes a much greater load on the inner rail, and, if a deficiency of cant is accepted for

the fast trains, the crushing of the table, and possible drawing of the fastenings, of the inner rail is reduced. More wear may be experienced on the outer rail, because it is a matter of experience that increasing the cant reduces the grinding of the outer wheels. The proportion of very fast trains is small, and an extra fastening on the inside of the outer rail will meet any danger of drawing.

To adhere rigidly to any table of normal speed on a given radius is a mistaken course. In rolling country a curve at a summit cannot be operated at such a high speed as a curve of equal radius in a hollow. On a double line a curve occurring on a gradient should not have the same cant on both lines. A compromise has always been made on single lines, and the deficiency has not resulted in accidents.

63.—Transition or Approach Curves.

The object of interpolating transition curves is to avoid the sudden effect of centrifugal force acting on a vehicle directly it reaches the tangent point of a circular curve, a point at which it is not correct to give the full cant. The cant must either be run out on the straight, or be gradually attained on a curve on which the centrifugal force at constant speed increases gradually in proportion to the curvature at any point. This is not strictly the case if there is a deficiency of cant on the circular curve, in modern practice, but the same length of transition is adhered to, as if the full cant in the equilibrium formula were allowed.

The equation to the true transition curve, in co-ordinates, is of the form

$$y = Mx^3(1 + ax^4 + bx^8 + cx^{12}, \text{ etc.})$$

The cubic parabola is an approximation to the true formula, provided that the angle BOD in Fig. 19 does not exceed about 9°, when the radius attains its minimum and begins to increase again. The following approximations may be used.

$Y =$ ordinate at the common tangent $= L^2/6R$

$S =$ shift inwards of the whole circular curve $= L^2/24R$

$OF = 2L/3$.

The values of the versines are given in Art. 64.

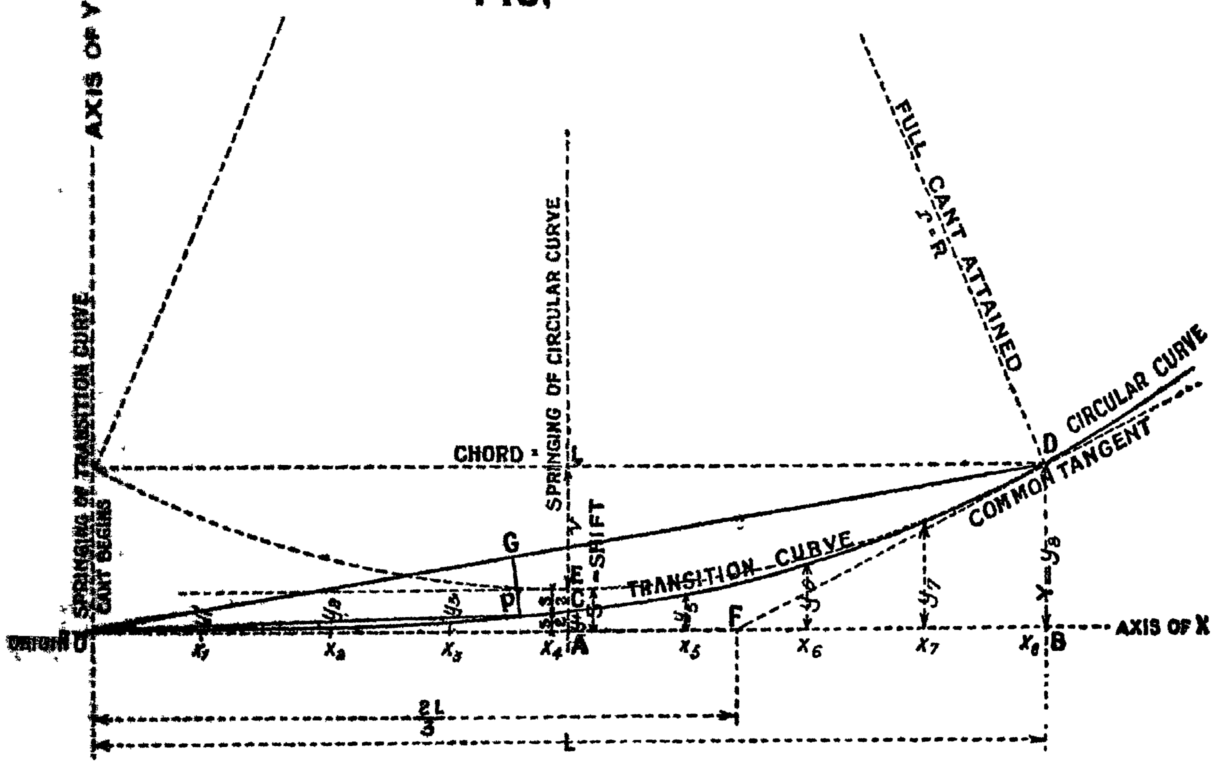
In string lining, the best compromise is made, but the final result will hardly be as exact as if the transitions at each end and the circular curve had been originally set out. The shift inwards of the circular portion may bring the track to the inner edge of the formation.

It is important to settle the length of the transitions, which have a length of twice the arcs cut off from the original circular curve, one at each end. A certain cant gradient may be taken, involving a certain increase in cant per unit length. If there be no deficiency allowed, this may be an inch in a rail length, 1 in. in 360 in. or a gentler gradient. On L.M.S. tracks run over by the Coronation Scot at 80 to 90 m.p.h., the transition lengths have a minimum length of five half-chords, a chord measuring 1·61 ft. multiplied by the maximum speed in m.p.h., and the cant is run up at 1 in. per half-chord. On the Great Western of England, for unrestricted speed the cant gradient is an inch in 120 ft. Where there is a quadruple track, with extra spacing, the transitions will require careful planning, and the problem becomes easier if the fast tracks lie outside the slow tracks.

While these considerations must be given weight, it is desirable to take a multiple of the rail length as the length of transition, and to arrange that one or more steps on the inchboard used for cross-levelling shall give the increase of cant per outer rail length, or half-chord taken in string lining. The full cant should also be so many steps on the inchboard.

It is simple enough to take the transition length as a multiple of rail length at one end of the circular arc, but, unless length of the circular arc also is a multiple, certain complications will arise at the other end of the circular arc, because the joints will not fall in the same relative positions for running up the

FIG. 19



AXIS OF Y
SPRINGING OF TRANSITION CURVE
CANT BEGINS
SPRINGING OF CIRCULAR CURVE
FULL CANT ATTAINED
r = R
CIRCULAR CURVE
COMMON TANGENT
CHORD = L
TRANSITION CURVE
SHIFT
G
P
E
C
D
F
ORIGIN O
A
B
AXIS OF X
x1
x2
x3
x4
x5
x6
x7
x8
y1
y2
y3
y5
y6
y7
Y = y8
2L/3
L

cant. There are two remedies, both of which may be required. A pair of short rails may be interpolated, or the radius may be slightly altered, so that the length along the outer rail may be a multiple of the rail length.

64.—String Lining.

In adjusting the results of measurement, as carried out in Art. 31, to obtain as smooth a curve as possible, certain principles must be grasped :.

I. It can be proved that the sum of the versines, including those of the transitions, must be constant. The sum of the changed versines must agree with this figure. Therefore, the sum of the amounts of change, plus or minus taken together, must be zero.

II. A decrease of the versine tends to throw the curve following it outwards, and an increase inwards. This has an application if a length of straight has to be interpolated for a turnout from a curve (Art. 56).

III. An increase or decrease of one unit to a versine slews the next station two units, the next station but one four units and so on, with a cumulative effect throughout the remainder of the curve, unless or until there is another change of measured versine, and this again becomes cumulative. Interpolation of a transition affects the whole curve.

IV. In the final result, the slew, and also half the slew, must be zero, otherwise the realigned curve will no longer be tangential to the following straight.

The measured versines should be plotted graphically by offsets from a datum line, on which the stations are plotted at equal distances. The scale for the offsets will be distorted for facility of plotting. An idea can thus be obtained, by drawing a trial line, of changes to be made in the versines, but the areas above the original line as plotted should nearly equal the areas below the line.

A graphical method of adjustment was given by Mr. W. H.

Shortt in Selected Paper No. 3, Inst. C.E., and another in P.W.I. Journal, Vol. LI, Part I In the same Journal the method of M. Hallade for an analytical calculation is given. This involves a consideration of the "Moments" induced by cumulative effect, but the calculation is made easier in Bartlett's method. This has been published in "String Lining Made Easy" (Simmons Boardman), also in "String Lining of Railway Curves," by P.E. Knight (Railway Gazette). A series of articles by the Author of this work appeared in the Railway Engineer, 1929 Bartlett's method is recommended, although experience will be necessary before rapidity can be expected.

The measured versines in units are entered opposite their respective stations on a slate. In the next column comes the changes proposed, by reference to the diagram mentioned above. In a fourth column come the differences, plus or minus, obtained by deducting always the proposed versines from the measured versines. In the fifth column comes the sum of the differences up to date, including therefore the cumulative effect up to date. In the last column is the half slew at the station, to be doubled when slewing on the ground.

A. To obtain the sum of differences at Station 10, the sum at Station 9 is added to the difference at Station 10, with due regard to sign.

B. To obtain the half-slew at Station 10, the half-slew at Station 9 is added to the sum of differences at Station 10, again with due regard to sign. A plus result requires slewing out and a minus result slewing in.

C. There will almost certainly be a residual half-slew at the last Station, or perhaps opposite a fixed structure, on first working out. The cumulative effect must be remembered. The adjustment may be quickly made by taking one or more pairs of Stations, giving two units more (or less) at the first and one unit less (or more) at the second so that the residue is removed. It is seldom possible to adjust over a few Stations.

In selecting pairs of stations neither must be one of those included in the transitions. The versines in these must follow fixed principles.

The offset from a tangent to a transition curve at any Station is equal to the cube of the number of the Station (1, 8, 27, 64, etc) divided by the cube of the number of Stations in the transition length L, and multiplied by $L^2/6R$.

Thus, at Station 3 in a four Station transition, $o = 27/64 \times L^2/6R$, and at Station $4 = 64/64\ L^2/6R$.

The versines, for practical purposes, run in a series, for a four Station transition, 1 (at the springing), 6, 12, 18, 23, 24 (circular curve), all multiplied by $L^2/6R$, and divided by 128 (*twice* the cube of the number of the Stations). The series is extended in a six Station transition 30, 35, 36 (circular curve), but the divisor is 432. The versines will be expressed in the units adopted for measurement.

The sum of the versines of a transition is greater, therefore, than the sum of the versines of the circular portion of the curve replaced by the transition This is the reason for the "shift," see Art. 63. It may be embarrassing to use a long transition in realignment

Shortt's graphical method requires a long sheet of squared paper. He devised an earlier method about 1909, which may be useful in a preliminary revision of a curve in difficult country or if there are many structures, using distorted scales. The principle for selection of scales is that

$R/L = L/D = 10$, where R is curve-radius, L rail length, and D versine. Thus the scales may be, for R, 200 ft., for L, 20 ft., and for D 2 ft., to the inch. For long curves of small radius R/L may be equated to 5, the scales becoming respectively 200, 40, and 8 ft. to the inch.

A method of calculation for extensive regrading, in cases where ballast is largely deficient, was worked out, similarly to the string lining method, by the Author in the Railway Engineer for December, 1930.

65.—To Set out a Diversion.

Assume the lay-out to be symmetrical, as in Fig. 20, all curves being probably the sharpest allowed with pieces of straight in between of 100 to 200 feet in length.

Rule.—To find L the length of each half of the diversion, add together S^2, the square of the straight portion between the reverse curves, and 4 RD the product of four times the radius into the maximum offset of the diversion from the main line; subtract D^2, the square of the maximum; and take the square root of the result.

To find the tangent T, divide RD, the product of the radius into the maximum offset, by L + S, the sum of the half of the diversion and the length of straight between the reverse curves.

Formulæ —

$$L = \sqrt{(S^2 + 4RD - D^2)}$$

$$T = \frac{RD}{(L + S)}$$

Directions.—From the middle point of the line which is to be diverted, set off the predetermined offset D. From the middle point of the diversion thus determined, measure parallel to the main line and in both directions the tangent lengths T. This fixes on each side one extremity of the common tangent lines. From the middle point of the line which is to be diverted measure back along the line in both directions the half-length L. This determines the beginning and the end of the diversion, from each of which again the distance T must be measured back along the line, to fix on each side the other extremity of the common tangent lines. These common tangents may now be lined in, and the four tangent lengths T measured off, leaving the required length of straight S in the middle.

If necessary, a piece of straight may be allowed for at the

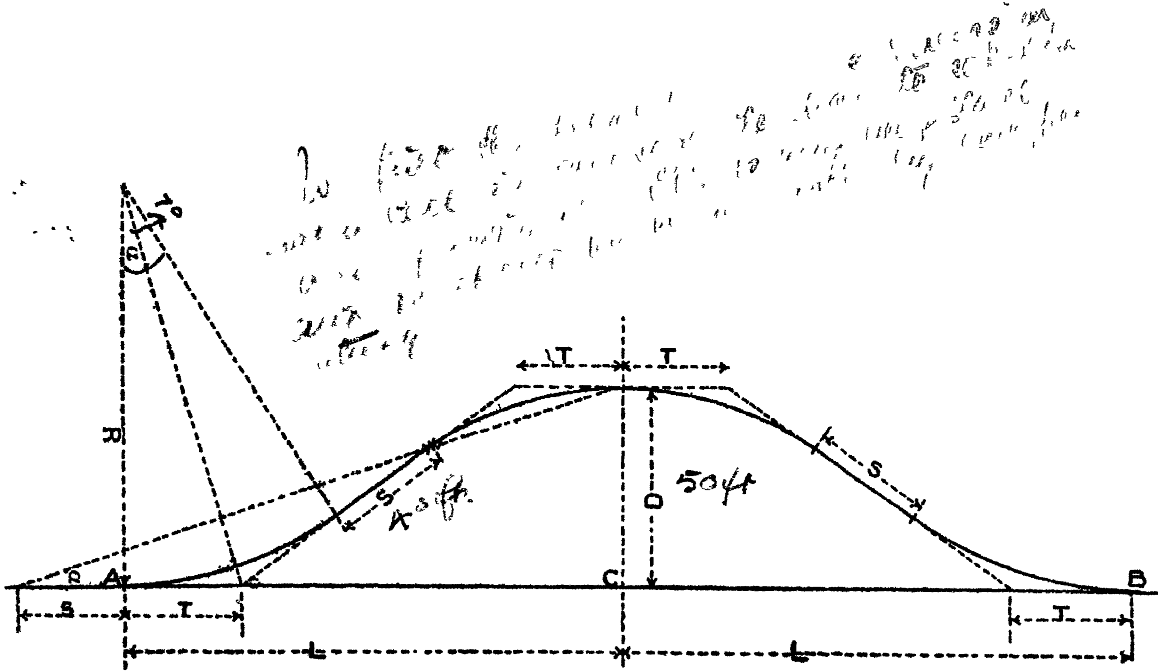


FIG 20

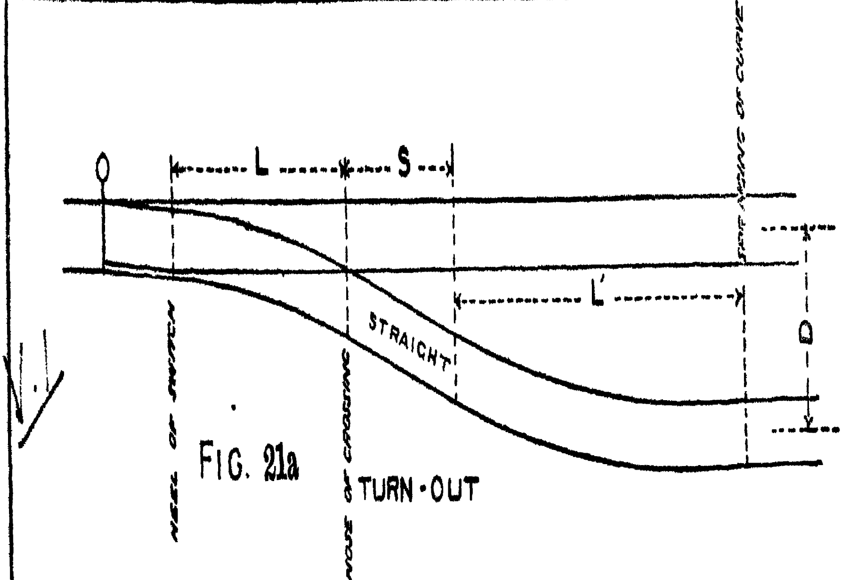


FIG. 21a

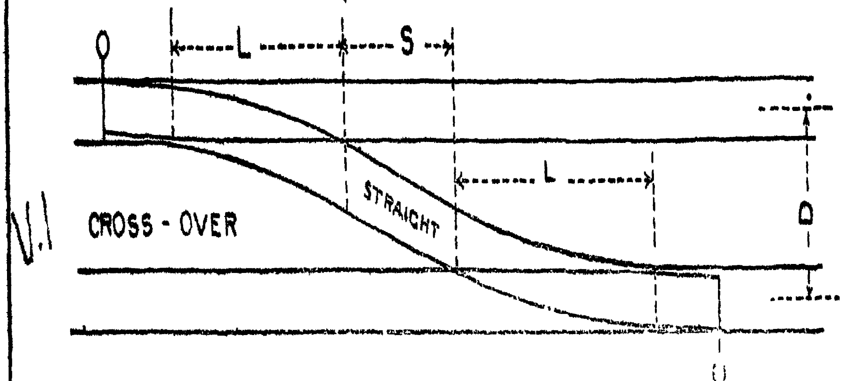


FIG 21b

middle of the diversion opposite C, making the whole length of the diversion by so much longer.

66.—Turnouts and Crossovers.

A turnout from one line to another (Fig. 21a) is made by means of a pair of switches, a crossing, and a reverse curve running in the direction of the second line, with or without an intermediate portion of straight line.

When a turnout enters the other line by means of a second crossing, and a second pair of switches, it becomes a cross-over (Fig. 21b).

The whole length of a turnout is made up of:

(*a*) Length of tongue,
(*b*) Lead of crossing (L),
(*c*) Intermediate portion (S), straight or curved,
(*d*) Curve-lead (L′), any radius may be used;

while that of a crossover is made up of—

(*a*) Length of tongue,
(*b*) Lead of crossing (L),
(*c*) Intermediate portion (S), straight or curved,
(*d*) Lead of crossing (L), possibly of different number,
(*e*) Length of tongue.

67.—Gathering Line.

In Fig 22, let

S = distance from nose to nose of crossings, measured in the direction of the parallel roads.
V = the same, measured in the direction of the gathering line.
D = distance between parallel roads, centre to centre.
a = angle of crossings,
θ = angle which the gathering line makes with the parallel roads.

Then,

$$V = D \ cosec \ \theta \qquad S = D \ cot \ \theta$$

$$T = R \ \tan\left\{\left(\frac{(\theta - a)}{2}\right)\right\} \quad Y = \frac{T \sin a}{\sin \theta} \quad Z = \frac{T \sin (\theta - a}{\sin \theta}$$

To find the position of the crossings, measure Z, as indicated, from the intersections of the gauge-lines of the parallel roads with the gathering line.

The measurements Y and T will give the points necessary for lining in the continuations of the curves beyond the crossings.

When θ = "the limiting angle," i e. the greatest angle at which the gathering line can be run across the parallel lines, each crossing fits against the butt of the next stock rail, if the gathering line be indefinitely extended, the tracks being equidistant, each crossing in succession will occupy a similar position. It will be found, however, that the road next to the running road will lie at a greater distance than D, in some cases.

To find θ the limiting angle, V must be equal to the sum of the length of the crossing behind the nose, the tongue, that part of the stock rail which lies beyond the toe of the tongue and butts against the crossing, and the lead, while D must be equal to the distance between roads.

Part of the stock rail can be cut off to make the angle still greater, and also part of the point rail and splice rail of the crossing.

When the gathering line runs across the parallel lines at the angle of the crossings, $\theta = a$ and

$$V = D \text{ cosec } a \quad \text{and} \quad S = D \text{ cot } a$$

68.—Crossing more than One Line—Diamond Crossing.

The turnout curve may be continued to cross a parallel track, or more than one, if the turnout occurs at a junction (Fig. 23). To determine the numbers of the successive V

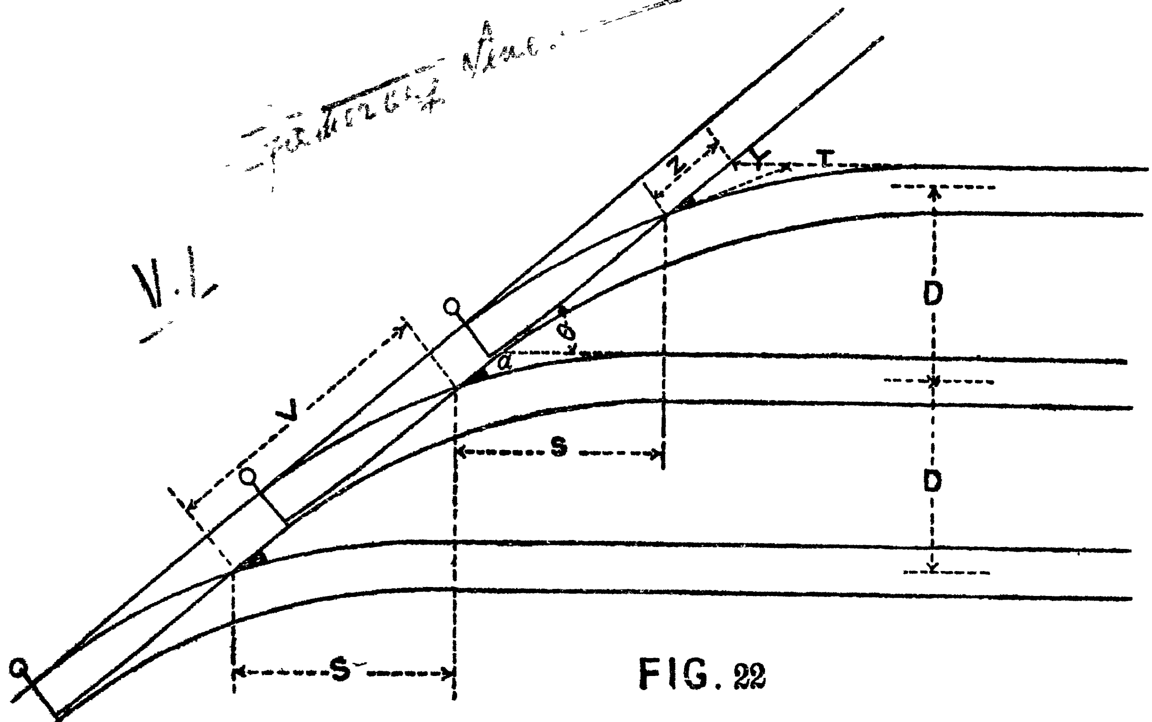


FIG. 22

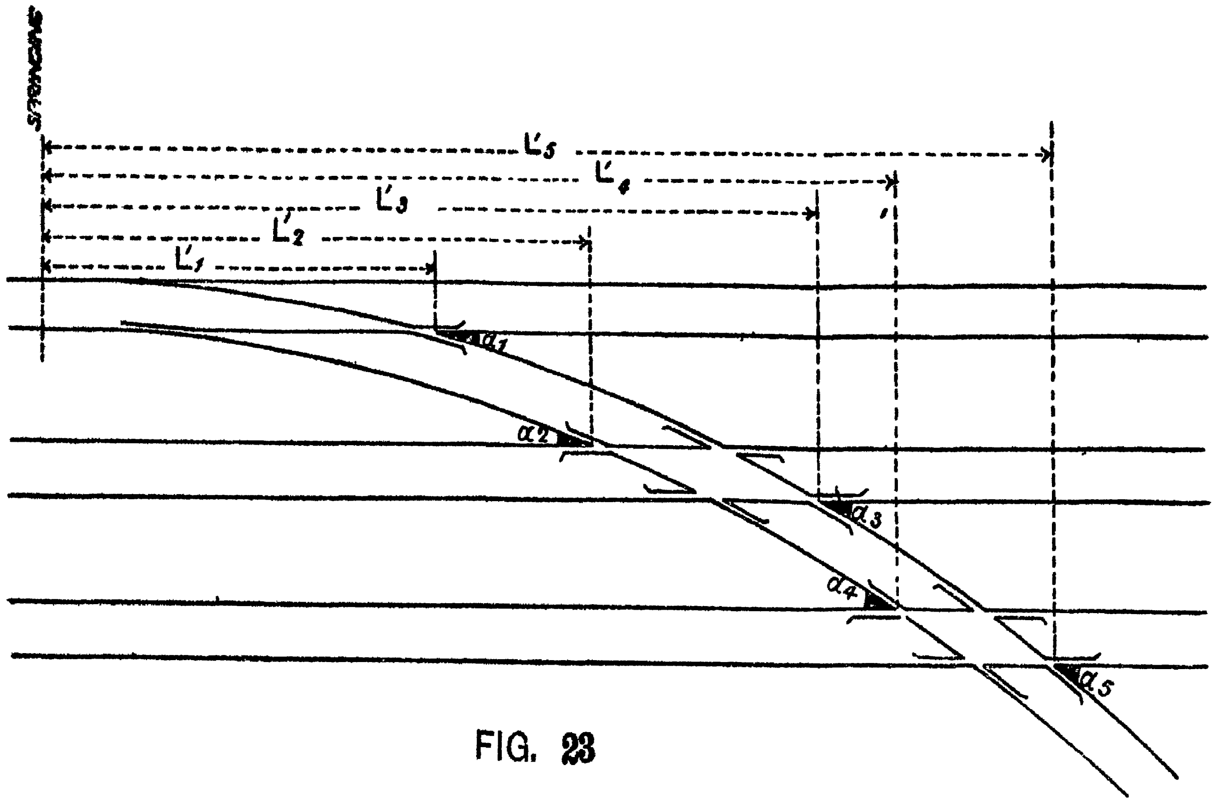


FIG. 23

crossings in the rails, we transpose the formula in Art. 48,

$$D = R \text{ versine } a \quad \text{into} \quad \text{versine } a = D/R.$$

D, contains an element $\pm$ o, the offset, inside or outside the gauge line of the track, to the springing of the turnout curve.

If C be the distance centre to centre of tracks, the ordinates in succession will be :—

At No. 2 crossing, $C - o$; at No 3 crossing, $D + C$; at No. 4 crossing, $2\,C - o$, and for No. 5 crossing, $2\,C + D$.

These ordinates will be substituted for D in the formula, to find the angles of the crossings

We calculate the successive curve leads corresponding to the angles of V crossing by the formula (Art. 48) $L = R \sin a$. Similarly, the angles of the diamond crossings can be calculated For accuracy, the radius $R - G$ for the inner rail should be taken for all crossings where the inner rail crosses other rails.

The crossings may differ in number. In one actual example, the first V crossing was 1/9·5, the obtuse crossings 1/8 and the other V crossing 1/7. This results in better running than a symmetrical diamond, to which the turnout curve can be joined by a transition curve.

69.—Single and Double Slips.

A symmetrical diamond is practically demanded if slips are to be got in, as shown in Figs. 24 and 25. On the 5 ft. 6 in. gauge with a 1 in $8\frac{1}{2}$ diamond AC is 94 ft.

$BC/AC = \cos\,(90° - a/2)$ and $AC = G \operatorname{cosec} a/2$.

$T \;\; = G \operatorname{cosec} a$

$DE = T - l'$ (tongue length, plus projections of the stock rail and the crossing behind the theoretical nose). It does not follow that the curve of the slip will be tangential to the gauge line DA, but any offset may be ignored. The curve, tangential to one tongue at the heel, will have a radius

$R = (D - d) / [\cos b - \cos\,(a - b)]$

$D = G - l' \operatorname{cosec} a.$

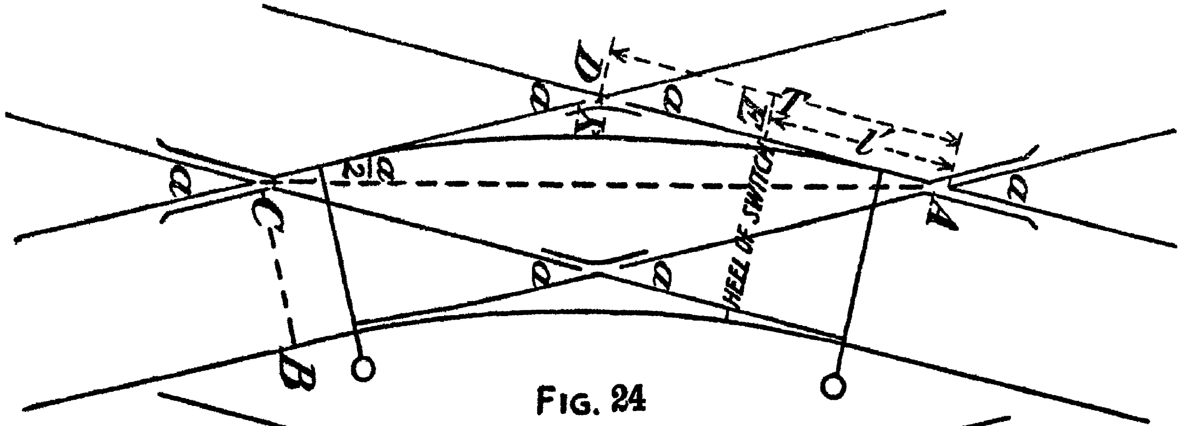


FIG. 24

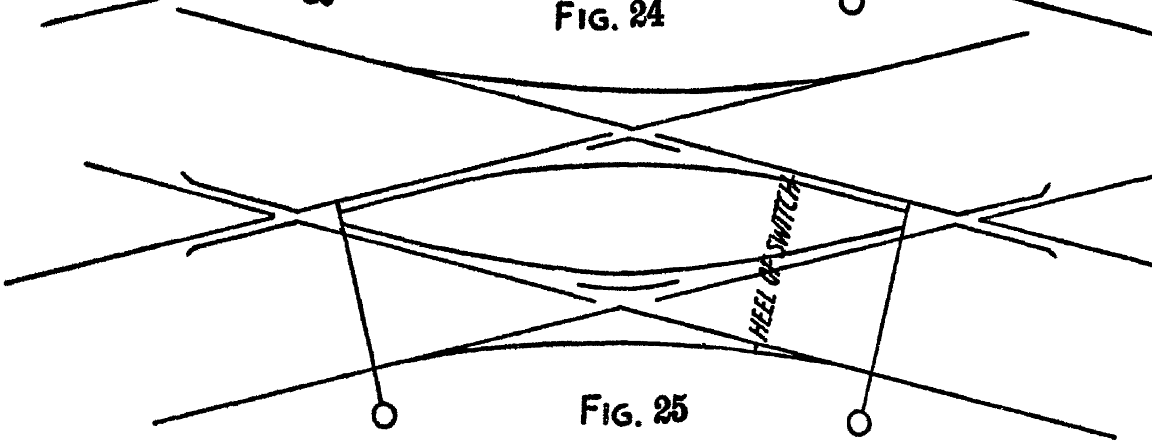


FIG. 25

From the exsecant $Y = R (\sec a/2 - 1)$ must be deducted the offset o, to be calculated, if the centre point of the slip curve is to be found for better lining.

In Fig. 25 a set of double slips is shown, but the points are not usually set for the cross roads Normally, the tongues at the V crossings are connected by a knuckle joint, so that when one is open the other is shut

70.—Three Throw Points.

These are seldom used. Special crossings will have to be used, as the standards will seldom fit the needs of the case. Three throw points are most likely to be required for "king-switches" in large marshalling yards below the hump, but the traffic is hardly likely to be so symmetrical that the loss of 100 feet or so by using tandem turnouts on one side of the yard would be a serious matter.

TABLE

BRITISH STANDARD RAIL SECTIONS

APPENDIX

STANDARD DIMENSIONS FOR INDIAN RAILWAYS WITH ALLOWANCE FOR CURVATURE

TABLE I

BRITISH STANDARD RAIL SECTIONS

(*a*) Bull-head Rails (Report 9/1935)

Weight.	Depth of Rail.	Width of Head.	Depth of Head.
lb	in.	in.	in.
60	$4\frac{3}{4}$	$2\frac{15}{16}$	—
65	$4\frac{7}{8}$	$2\frac{3}{8}$	—
80	5	$2\frac{[illegible]}{16}$	—
75	$5\frac{1}{8}$	$2\frac{1}{2}$	—
80	$5\frac{3}{8}$	$2\frac{9}{16}$	—
85 R	$5\frac{15}{32}$	$2\frac{11}{16}$	$1\frac{13}{16}$
90 R	$5\frac{35}{64}$	$2\frac{3}{4}$	$1\frac{55}{64}$
95 R	$5\frac{23}{32}$	$2\frac{3}{4}$	$1\frac{15}{16}$
100	$5\frac{29}{32}$	$2\frac{3}{4}$	$2\frac{23}{32}$

(*b*) Flat-bottom Rails (Report 11/1936)

Weight.	Depth of Rail.	Width of Head	Depth of Head.	Width of Foot.	Section Modulus
lb	in	in	in	in	in
25 R	$2\frac{7}{8}$	$1\frac{1}{2}$	..	$2\frac{3}{4}$	1·88
30 R	$3\frac{1}{8}$	$1\frac{5}{8}$	..	3	2·44
35 R	$3\frac{3}{8}$	$1\frac{3}{4}$	..	$3\frac{1}{4}$	3·10
40 R	$3\frac{5}{8}$	$1\frac{7}{8}$	..	$3\frac{1}{2}$	3·77
45 R	$3\frac{7}{8}$	$1\frac{31}{32}$	.	$3\frac{3}{4}$	4·55
50 R	$4\frac{1}{8}$	$2\frac{1}{16}$	$1\frac{19}{64}$	$3\frac{15}{16}$	5·43
55 R	$4\frac{5}{16}$	$2\frac{5}{32}$	.	$4\frac{1}{8}$	6·22
60 R	$4\frac{1}{2}$	$2\frac{1}{4}$	$1\frac{13}{32}$	$4\frac{5}{16}$	7 04
65 R	$4\frac{11}{16}$	$2\frac{5}{16}$	..	$4\frac{7}{16}$	7·79
70 R	$4\frac{7}{8}$	$2\frac{3}{8}$	.	$4\frac{5}{8}$	8 73
75 R	$5\frac{1}{16}$	$2\frac{7}{16}$	$1\frac{9}{16}$	$4\frac{13}{16}$	9·72
80 R	$5\frac{1}{4}$	$2\frac{1}{2}$	..	5	10 75
85 R	$5\frac{7}{16}$	$2\frac{9}{16}$	..	$5\frac{3}{16}$	11·61
90 R	$5\frac{5}{8}$	$2\frac{5}{8}$	$1\frac{13}{32}$	$5\frac{3}{8}$	13·05
95 R	$5\frac{13}{16}$	$2\frac{11}{16}$	..	$5\frac{9}{16}$	14·22
100 R	6	$2\frac{3}{4}$	..	$5\frac{3}{4}$	15·37
105	$6\frac{1}{8}$	$2\frac{13}{16}$	..	$5\frac{7}{8}$	16·57
110	$6\frac{1}{4}$	$2\frac{7}{8}$	$1\frac{15}{16}$	6	17·48
115	$6\frac{3}{8}$	$2\frac{15}{16}$	..	$6\frac{1}{8}$	18·50
120	$6\frac{1}{2}$	3	..	$6\frac{1}{4}$	19·73

The foot of a bull head rail is as wide as the head. The section moduli of these rails were not worked out.

APPENDIX A

STANDARD AND RECOMMENDED DIMENSIONS FOR INDIAN RAILWAYS

NOTE.—The following are abstracted from a large number of dimensions for the use of Permanent Way Inspectors. The other dimensions rather concern the Engineer, and the Inspector will seldom be required to check them, except in the case of tunnels, which are rarely included in his length.

The dimensions in width will require to be increased as noted in Appendix B.

Item.	Gauge.							
	5′ 6″		Metre.		2′ 6″		2′ 0″	
		R		R		R		R
1. Formation, single line—								
Minimum width, embankment	.	20′ 0″	..	16′ 0″	10′ 0″	12′ 0″	9′ 0″	10′ 0″
Do, do. Cutting (excludes side drains) .	..	18′ 0″	..	14′ 0″	9′ 0″	11′ 0″	8′ 0″	9′ 0″
2. Spacing of Tracks—								
Minimum distance c. to c. of tracks, outside stations.	14′ 0″	..	12′ 0″	.	11′ 6″	.	11′ 0″	..
Do. do. in station yards, passenger .	14′ 0″	..	14′ 0″	.	13′ 6″	.	13′ 0″	.
Do. do. not adjoining passenger tracks	14	.	12′ 6″	14′ 0″	12′ 6″	14′ 0″	12′ ″0	12′ 6″
3. Maximum Degree of Curvature, on Main Line—								
For unrestricted Speed allowed on the gauge . .	..	.	..	..	10°	.	16°	..
In any circumstances . .	10°	.	16°		40°	.	60°	..
Corresponding radii . . .	..	..	.		573	.	358	..
feet . . .	573	..	358	.	143	..	96	.

Standard and Recommended Dimensions for Indian Railways—*contd*

Item.	Gauge							
	5′ 6″		Metre.		2′ 6″		2′ 0″	
		R		R		R		R
4. Timber Cross Sleepers—								
Minimum length ft.	..	9	.	6	.	5	.	4
Do. breadth in.	..	10	.	8	..	6	..	6
Do. depth in	.	5	.	4¼	..	4	.	4
Spacing on longitudinal girders between edges .	.	1′ 8″	..	10″		10″	..	6″
5. Ballast—								
Width at foot of rail . . .	..	11′ 0″	..	7′ 6″	..	6′ 0″		5′ 0″
Depth below sleepers—inches .	.	8	.	8	..	6	..	6
6. Rails—								
Minimum clearance of a check rail on a curve, inches .	1¾	..	1⅝	.	1 7/16	..	1¼	..
Note.—Increase the clearance by half increase of gauge for curvature.								
Do. do. at a level crossing, inches .	2	..	2	..	2	..	1⅞	..
Maximum do. do.	2¼	..	2¼	..	2¼	..	2¼	..
Depth allowed for wheel flange .	1½	..	1⅜	..	1¼	..	1⅛	..
7. Buildings and Structures—								
Minimum Horizontal Distance from centre of track to any structure from rail level to x feet above rail x = .	1′ 0″	..	1′ 0″	..	0′ 9″	..	1′ 0″	1′ 0″
	5′ 6″	..	4′ 6″	6′ 3″	4′ 0″	6′ 3″	4′ 0″	4′ 5″

Standard and Recommended Dimensions for Indian Railways—*contd.*

Item	Gauge. 5′ 6″		Metre		2′ 6″		2′ 0″	
		R		R		R		R
7. Buildings and Structures (*contd.*) Do. do. do. from x feet above to y feet above rail (except a platform) x as above, y =	14′ 6″ 7′ 0″	..	10′ 6″ 6′ 3″	.	9′ 6″ 6′ 0″	.	9′ 0″ 5′ 9″	10′ 6″ 6′ 3″
Note —Add allowance for curvature, see Appendix B.								
Minimum height above rail* . .	16′ 0″	.	12′ 6″	..	12′ 6″		11′ 0″	12′ 6″
8. Platform—								
Centre of Track to edge of coping .	5′ 6″	.	4′ 5″	.	4′ 0″	..	3′ 9″	..
Do. do to face of wall . . .	6′ 3″							

* 17′ 9″ for electric traction.

For Wheels and Axles and Clearances affecting points and crossing see Article 54.

APPENDIX B

ADDITION TO STANDARD DIMENSIONS FOR CURVATURE

The under frame of a vehicle, standing on a curve, will take up a position along a chord to that curve over so much of the length of the vehicle as lies between the axles, or pivots of the bogie bolsters, as the case may be. The outer corners of the underframe will project further from the centre of the track than if the vehicle were standing on a straight track.

An addition to Standard Dimensions therefore has to be made, both on the outside and on the inside of the curve. The addition on the inside is equal to the versine of a chord equal to the distance between axles or bogie centres. The addition on the outside is equal to the *difference* between the versine due to the overall length and the length between bogie centres.

The lengths of body, and bogie centre distances adopted for calculation by the Railway Board of India are, for the various gauges, at present :—

Gauge.	Length.	Bogie centres.
5′ 6″	68	48′ 0″
metre	64	45′ 0″
2′ 6″	45	33′ 9″
2′ 0″	40	30′ 0″

Since, however, vehicles moving at speed "lurch" to a certain extent, a further addition has to be made for this on the outer sides. On double track, there may be a lurch towards each other of the outer corners in the one case and the centre sections of the vehicles in the other.

If abutments of overbridges are "battered" no addition may be necessary, and signal posts may be tilted to avoid the addition, but wherever there is a curve the Inspector must pay attention to the possibility of addition to Dimensions If an obstruction *between tracks* cannot be tilted, a water column for instance, then the allowance for the outside must be added to the allowance for the inside to arrive at the extra clearance (plus the width of obstruction).

INDEX

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